Supporting Calculations for the Transportation Analysis of the Programmatic Alternatives in the GNEP PEIS

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1. INTRODUCTION

This report summarizes the methods and input data DOE used to estimate the potential impacts to workers and public from shipments of radioactive materials as described in the GNEP PEIS.

The organization of this report is as follows:

- Section 2 describes the methods and data used to estimate impacts during loading operations;
- Section 3 provides the routing methodologies;
- Section 4 provides the radionuclide inventories and shipment configuration data used to estimate impacts;
- Section 5 presents the methods and data used to calculate incident-free transportation impacts; and
- Section 6 provides the methods and data used to estimate the transportation accident risks;
- Section 7 provides the methodologies and data used to analyze severe transportation consequences; and
- Section 8 provides the references sited in this report.

2. IMPACTS FROM LOADING OPERATIONS

2.1 Radiological Impacts from Loading Operations

Loading operations typically represent the largest exposure impacts involved with the transportation of nuclear materials. As in the Yucca Mountain FEIS and SEIS (DOE 2002i and DOE 2008f), DOE assumed that exposure due to loading operations would total approximately 0.432 person-rem and 0.663 person-rem for truck and rail spent nuclear fuel casks respectively. The values provided in the Yucca Mountain documents are based upon actual exposure values provided in industry documents detailing loading operations of commercial spent nuclear fuel (BMI 2007).

Estimation of loading operation impacts of other materials and waste products was based on the size and number of packages per load. Table 1 provides the input parameters for estimation of impacts of loading operations for non-spent fuel domestic programmatic materials. The loading parameters provided in table represent the per-shipment requirements. A truck shipment is comprised of one trailer. Most rail shipments are comprised of five rail cars. The loading parameters provided in Table 2-1 are entered as inputs for use in the RADTRAN 5.6 calculations. It is assumed that the five workers are at a distance of 6.6 ft (2 m) from the radioactive source.

2.2 Industrial Impacts from Loading Operations

Based on the loading operations estimates for PWR and BWR casks, loading of LWR spent fuel would require 17.9 and 16.2 worker-years respectively (based on a 251-day work year). For the other materials analyzed, it was assumed that each rail car loaded would require 5 workers involved in loading operations for a duration of one 8-hour shift. This yields a total of 1,400 work days per year, or 5.6 worker-years. Together with the LWR spent fuel loading, a total of 39.7 worker-years would be spent in loading operations. For the analysis, this was rounded up to 40 worker years spent per year. Using the assumption that the noninvolved workforce would be 25 percent of the total workforce, DOE determined that uninvolved workers would spend 10 worker-years during loading activities for uninvolved workers.

DOE based incidence and fatality rates for involved workers on Bureau of Labor Statistics data for 2005 (BLS 2006 & BLS 2007). These data are organized into industries. DOE used data for workers in the transportation and warehousing industries to estimate impacts because they closely represent the hazards associated with loading casks and shipping containers. For noninvolved workers, DOE based the rates on the professional and business services industries.

For vehicle emission fatalities, DOE based the analysis on industrial safety impacts of an automobile emission fatality rate of 9.4×10^{-12} fatalities per km per persons per km^2 and on a representative rural population density of 6 persons per km^2 (DOE 2004f). For traffic fatalities, the Department based the analysis of industrial safety impacts on a fatality rate of 1.0×10^{-8} fatalities per km (FMCSA 2007) over the period from 2001 to 2005. DOE also based the analysis on workers driving 23 mi (37 km) round trip for 251 days per year. Table 2.2-1 provides the inputs used to calculate the industrial safety impacts due to loading impacts at the AFCF. Table 2.2-2 provides the results of the analysis.

TABLE 2.1-1—*Per-Shipment Loading Parameters for Domestic Programmatic Alternatives*

Material Type	Number of Handlers	Loading Time (hr)
Legal-Weight Truck Scenario		
Spent fuels [a]	13	10
Fresh fuels	13	10
Am oxide product	5	12
Cm oxide product	5	12
Consolidated TRU/U product	5	12
Cs/Sr waste	5	8
Ln/fission product waste	5	4
Tc/UDS/hulls waste	5	4
GTCC LLW	5	4
LLW and MLLW	5	12
Recovered uranium (oxide)	5	12
Recovered uranium (metal)	5	8
Mostly-Rail Scenario		
Spent fuels	13	90
Am oxide product	5	60
Cm oxide product	5	60
Cs/Sr waste	5	40
Ln/Fission Product waste	5	20
Tc/UDS/hulls waste	5	20
GTCC LLW	5	20
LLW and MLLW	5	60
Recovered uranium (oxide)	5	60
Recovered uranium (metal)	5	40

[a] The loading impacts are equal to the loading impacts provided in the Yucca Mountain SEIS (DOE 2008f). The loading operations in the Yucca Mountain SEIS assume a crew of 13 workers conducting multiple tasks at various distances to the source and for various times.

TABLE 2.2-1—*Data Used to Estimate the Industrial Safety Impacts to Workers for Loading Operations*

Quantity	Value	Reference
	Involved Workers	
Worker-years	30	Calculated
Total Recordable Cases Rate	0.082 per worker-year	BLS 2006, for warehousing and storage industries
Lost Workday Cases Rate	0.0054 per worker-year	BLS 2006, for warehousing and storage industries
Fatality Rate	1.76×10^{-4} per worker -year	BLS 2007, for transportation and warehousing industries
	Noninvolved Workers	
Worker-years	10	Calculated
Total Recordable Cases Rate	0.024 per worker-year	BLS 2006, for professional and business services, management of companies, and enterprises
Lost Workday Cases Rate	0.012 per worker-year	BLS 2006, for professional and business services, management of companies, and enterprises
Fatality Rate	3.5×10^{-5} per worker -year	BLS 2007, for professional and business services
Automobile Emission Fatality Rate	9.4×10^{-12} fatalities/km per person/km^2	DOE 2004f
Traffic Fatality Rate	1.0×10^{-8} fatalities per km	FMCSA 2007, Table 2

TABLE 2.2-2—*Estimated Annual Industrial Safety Impacts to Involved and Noninvolved Workers during Loading Operations*

Worker Category/Impact	Impact
Involved Workers	
Total Recordable Cases	2.46
Lost Workday Cases	1.62
Industrial Fatalities	5.28×10^{-3}
Automobile Emission Fatalities	1.04×10^{-8}
Traffic Accident Fatalities	1.11×10^{-5}
Noninvolved Workers	
Total Recordable Cases	0.24
Lost Workday Cases	0.12
Industrial Fatalities	3.5×10^{-4}
Automobile Emission Fatalities	3.48×10^{-9}
Traffic Accident Fatalities	3.7×10^{-6}

3. ROUTING METHODOLOGIES

DOE used the TRAGIS computer program (Johnson and Michelhaugh 2003) to identify the representative rail and truck routes used in the analysis. TRAGIS is a Web-based geographic information system transportation routing computer code. The TRAGIS rail network is developed from a 1-to-100,000-scale rail network derived from the United States Geological Survey digital line graphs. This network currently represents more than 150,000 mi (240,000 km) of rail lines in the continental United States and has over 28,000 segments (links) and over 4,000 intersections (nodes). All rail lines with the exception of industrial spurs are included. The rail network includes nodes for nuclear reactor sites, DOE sites, and military bases that have rail access. The rail network has been extensively modified and is revised on a regular schedule to reflect rail line abandonment, company mergers, short line spin-offs, and new rail construction.

The TRAGIS computer code predicts highway routes for transporting radioactive materials within the United States. The TRAGIS database is a computerized road atlas that currently describes approximately 240,000 mi (390,000 km) of roads. Complete descriptions of the interstate highway system, U.S. highways, most of the principal state highways, and a number of local and community highways are identified in the database.

The TRAGIS computer code calculates routes that maximize the use of interstate highways. This feature allows the user to determine routes for shipment of radioactive materials that conform to the DOT regulations, as specified in 49 CFR Part 397. The calculated routes conform to applicable guidelines and regulations and represent routes that could be used. The routes represent a reasonable prediction of future routes, or are typical of what would be used in the period of study. The code is updated periodically to reflect current road conditions and has been benchmarked against reported mileages and observations of commercial truck firms (Johnson and Michelhaugh 2003).

For all routes traveled by legal-weight truck and heavy-haul truck (inter-modal transfer vehicle used to transport rail SNF casks), the model assumed that highway route-controlled quantities of radioactive materials (HRCQ) carriers would be used, as specified by 49 CFR 397.101. The representative routes for HRCQ carriers selected by TRAGIS are mostly interstate highways or large U.S. highways.

To calculate rail routes, the TRAGIS computer program uses rules that are designed to simulate routing practices that have been historically used by railroad companies in moving regular freight and dedicated trains in the United States. The basic rule used to calculate rail routes causes the program to attempt to identify the shortest route from an origin to a destination. Another rule used in the program biases the lengths of route segments that have the highest density of rail traffic to make these segments appear, for purposes of calculation, to be shorter. The effect of the bias is to prioritize selection of routes that use railroad main lines, which have the highest traffic density. As a general rule, routing along the high traffic lines replicates railroad operational practices. A third rule constrains the program to select routes used by an individual railroad company to lines the company owns or over which has permission to operate. This rule ensures the

number of interchanges between railroads that the TRAGIS computer program calculates for a route is correct. The number of interchanges between railroads is a significant consideration when determining a realistic and representative route.
Another rule used in the TRAGIS computer program to calculate a rail route determines the sequence of different railroad companies whose rail lines would be linked to form the route. Because a delay and additional operations are involved in transferring a shipment (interchanging) from one railroad to another, in order to provide efficient service, railroads typically route shipments to minimize the number of interchanges that occur. Reducing the number of interchanges also tends to reduce the time a shipment is in transit. This practice is simulated in the TRAGIS computer program by imposing a penalty for each interchange that is identified for a route. The interchange penalties cause the TRAGIS computer program to increase the calculated length of routes when more than one railroad company's lines are linked. As a consequence, the algorithm used in the TRAGIS computer program to identify routes that have the least apparent length gives advantage to routes that also have the fewest interchanges between railroads and the fewest involved railroad companies.

Last, a rule in the TRAGIS computer program is designed to simulate the commercial behavior of railroad companies to maximize their portion of revenues from shipments. The effect of this behavior is that routing is often affected by originating railroads, who control the selection of routes on their lines to realize as much of a shipment's revenue as possible. The result is that originating railroads transport shipments as far as possible (in the direction of the destination) on their systems before interchanging the shipments with other railroads. This behavior is simulated in the TRAGIS computer program by imposing a bias on the length of the originating railroad's lines to give the railroad an advantage when calculating a route. In evaluating the length of the route, the model treats 1 mile of travel on the originating railroad as being "less" than 1 mile on other railroads (DOE 2008f).

3.1 Routing Analysis for Domestic Programmatic Alternatives

The locations of potential recycling facilities, advanced recycling reactors (ARR), and treatment storage and disposal (TSD) facilities used to manage the waste products have not been identified. To assess the impacts of material transportation relative to the individual programmatic alternatives, DOE derived average fractions of rural, suburban, and urban zones adjacent to the transportation route, including the population densities corresponding to the three zone types. These values were calculated by adding the route characteristics of the transportation analysis in the *DOE Programmatic Spent Nuclear Fuel Management and INEL Environmental Restoration and Waste Management Programs Final Environmental Impact Statement*, DOE/EIS-0203, or Spent Fuel EIS (DOE 1995e). The Spent Fuel EIS data set was chosen due to its large size (61 reactor origin sites and five DOE facility destinations) and its wide geographic coverage. The five DOE sites evaluated as destinations were Hanford, INL, NTS, ORR, and SRS. The 61 origin sites provide a diverse geographical array of sites throughout the continental U.S.

The routes were analyzed using the routing computer code WebTRAGIS (Johnson and Michelhaugh 2003). The routes were calculated using current routing practices and applicable routing regulations and guidelines. Route characteristics include total shipment distance between each origin and destination and the fractions of travel in rural, suburban, and urban population density zones. Population densities were determined using data from the 2000 census.

Table 3.1-1 provides the route characteristics used in the all-truck option analysis. Table 3.1-2 provides the all-rail route characteristics. The average values calculated from the Tables 3.1-1 and 3.1-2 data were used to calculate route characteristics for truck and rail transport over distances of 150, 500, 1500, 2100 and 3000 mi (241, 805, 2414, 3380 and 4828 km). The minimum value of 150 mi (241 km) was chosen as it represented the minimum shipment distance evaluated in the Spent Fuel EIS, the maximum distance evaluated in the EIS was approximately 3000 mi (4828 km). The intermediate values were chosen to provide comparison of other transportation distances. Table 3.1-3 provides a summary of the routing inputs used to analyze the transportations impacts related to the domestic programmatic alternatives.

For the Yucca Mountain FEIS (DOE 2002i), DOE entered the route distances of all the spent fuel shipment routes to be analyzed. The upper bound shipment was found to be 3,100 mi (5,000 km) long, and the median value was approximately 2100 mi (3380 km). Impacts for shipments over the other four distances were estimated to provide comparison over a wider spectrum of shipping campaign possibilities. The population density values for all 5 scenarios were updated to reflect census 2000 data.

TABLE 3.1-1—*Route Characteristics Used to Develop Domestic Programmatic Inputs [1] —Truck Option*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density (/km^2)	Suburban Population Density (/km^2)	Urban Population Density (/km^2)
Site 1	HAN	3421.8	947.1	90.2	11.7	299.7	2273.3
	INL	2850.6	857.5	78.2	12.4	300.9	2281.7
	NTS	3242.4	899.1	108.4	11.6	309.2	2345
	ORR	784.7	659.9	39.5	19.5	307.5	2106.7
	SRS	888.4	712.4	49.5	18.4	321.7	2170.9
Site 2	HAN	761.6	598.3	96	18.5	353	2372
	INL	2161.1	344.7	26.5	10.1	293.7	2228
	NTS	2552.9	386.3	56.7	9.5	313.9	2377.6
	ORR	511.3	373.3	52.9	18.6	330.7	2270.5
	SRS	761.6	598.3	96	18.5	353	2372
Site 3	HAN	3459.3	910.5	74	11.8	307.2	2221.1
	INL	2888.1	820.9	62.1	12.5	309.2	2221.7
	NTS	3269.5	842.4	81.3	10.3	310.1	2201.6
	ORR	274.5	272.4	10.9	20.6	316.4	1873.4
	SRS	378.2	324.9	20.8	17.6	346.3	2137.5
Site 4	HAN	3504.2	979.6	142.4	11.6	319.1	2533.8
	INL	2933	890	130.5	12.2	322.2	2562.6
	NTS	3324.8	931.6	160.7	11.5	329.3	2552.6
	ORR	607.1	653.8	104.7	19.8	360.3	2615.1
	SRS	710.8	706.3	114.6	18.3	370.8	2598.6
Site 5	HAN	3498	1002	92.6	10.7	314.6	2207.9
	INL	2926.8	912.3	80.7	11.2	317.1	2206.4
	NTS	3324.4	871.1	88.7	10	315.7	2231.7
	ORR	329.4	301.1	18.2	15.8	332.1	2152.6
	SRS	169.8	160.3	13.4	14.6	364.3	2324
Site 6	HAN	3377.5	946.9	97.1	11.6	302.1	2302.5
	INL	2806.3	857.2	85.1	12.3	303.5	2314.3
	NTS	3198.1	898.8	115.3	11.5	311.8	2365.2
	ORR	679.3	588.6	39.6	19.4	309.2	2163.2
	SRS	783	641.1	49.6	18.1	324.9	2215.9
Site 7	HAN	1567.9	230.6	26.8	8.1	301.2	2304.7
	INL	996.7	141	14.9	7.8	309	2374.2
	NTS	1388.5	182.6	45.1	7.3	348.3	2464.3
	ORR	1620	485.8	50.9	12.2	312.9	2228.8
	SRS	1784.4	703.2	90.5	12.7	338.2	2261.6
Site 8	HAN	1558.2	209.9	18.7	8	290	2181.6
	INL	987	120.3	6.7	7.7	290.7	2117.2
	NTS	1378.8	161.9	36.9	7.2	339.8	2437.4
	ORR	1656.4	493.5	55.7	12.2	313.3	2234.8
	SRS	1820.7	710.9	95.4	12.7	338.2	2263.5
Site 9	HAN	3377.7	890.5	80.8	11.7	294.4	2251.5
	INL	2806.5	800.8	68.9	12.3	295.1	2257.3
	NTS	3198.3	842.5	99.1	11.5	304.3	2334
	ORR	435.1	378.5	34.1	18.8	318.3	2301.4
	SRS	494.9	438.4	36.5	17.7	331.1	2339.1

1. Source: DOE 1995d and original calculations.

TABLE 3.1-1—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Truck Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density (/km^2)	Suburban Population Density (/km^2)	Urban Population Density (/km^2)
Site 10	HAN	3007.9	608.6	124.1	9.2	363.9	2399.2
	INL	2436.7	519	112.2	9.4	376.9	2418.5
	NTS	2351.1	514.3	123.2	8.4	371.2	2472.3
	ORR	947.7	542.8	50	16.5	327.4	2307.6
	SRS	955.2	586.4	66	16	339.1	2321.6
Site 11	HAN	3195.4	828.2	103.1	10.2	326.9	2270.8
	INL	2624.2	738.5	91.2	10.6	331.5	2277.7
	NTS	3021.5	695.2	98.2	9.4	330.5	2295.6
	ORR	141.1	184	26	22.2	367.2	2375.9
	SRS	155	90.9	10.9	16.7	333.4	2054.3
Site 12	HAN	3597.2	974.3	81.3	12	302.2	2230.7
	INL	3026	884.6	69.3	12.6	303.5	2232.9
	NTS	3417.8	926.2	99.5	11.8	311.5	2316.5
	ORR	456.5	392.7	19.6	19.8	293.4	2045.4
	SRS	463.2	319.9	16.3	16.3	319	2183.5
Site 13	INL	805.4	140.3	15.1	9.6	300.9	2184.1
Site 14	HAN	723.9	136.4	16.8	9.7	318.4	2195.2
	INL	84.8	20.8	2.2	9.1	367.7	2317.9
	NTS	807.7	181.3	47.1	9.2	364.5	2470.4
	ORR	2530.8	596.3	61.6	10.6	309	2228.5
	SRS	2695.1	813.8	101.3	11	331.9	2257.9
Site 15	HAN	2379.1	332.4	32.6	9.1	287.7	2267.3
	INL	1807.9	242.7	20.7	9.3	287.2	2295.7
	NTS	2199.7	284.4	50.9	8.7	315.7	2422.3
	ORR	909.3	472.8	42	17.6	304.4	2218.9
	SRS	1186.6	668.9	84.9	16.5	334.9	2264.8
Site 16	HAN	2308.2	277.2	30	7.6	292.5	2248.5
	INL	1737	187.5	18.1	7.3	294.1	2268.6
	NTS	2128.8	229.1	48.3	7.1	328.2	2418.9
	ORR	436	144.1	15.4	15.3	296.2	2286.9
	SRS	1066.2	647.8	86.2	16.6	343.8	2261.5
Site 17	HAN	2098.9	361.7	55.1	8.1	337.3	2307.2
	INL	1527.7	272	43.2	7.9	353.2	2331.8
	NTS	1410.2	159.8	19.8	6.9	306.3	2305.8
	ORR	1826.8	477.3	65.2	11	304.1	2256.8
	SRS	1990.8	692.7	103.8	11.5	332.2	2275.3
Site 18	HAN	3491.4	931.8	125.7	11.6	305.3	2632.9
	INL	2920.2	842.1	113.8	12.2	307	2676.3
	NTS	3312	883.7	144	11.5	315.2	2641.2
	ORR	594.3	605.9	87.9	20	342.3	2772.1
	SRS	698.1	658.4	97.9	18.5	355	2736.8
Site 19	HAN	3583	1088.5	112.6	11.9	307.9	2411.3
	INL	3011.8	998.8	100.7	12.5	309.6	2434.2
	NTS	3403.6	1040.4	130.9	11.8	316.5	2451.4
	ORR	658.6	776	111.7	20.5	365.5	2543.7
	SRS	762.4	828.5	121.7	19	374.1	2533.9
Site 20	HAN	916.1	338.6	65.4	11.9	359.1	2363.1
	INL	1145.3	209.7	56.3	8.1	365.9	2509.2
	NTS	886.7	188	88.4	9.1	360.6	2876.8

TABLE 3.1-1—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Truck Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density (/km^2)	Suburban Population Density (/km^2)	Urban Population Density (/km^2)
	ORR	3269.2	683.1	110.6	9.5	329.7	2370.3
	SRS	3433.6	900.6	150.3	9.8	345.3	2352.7
Site 21	HAN	2977.7	668.4	55.2	10.7	296.3	2235.2
	INL	2407.5	593.8	43.3	11.2	297.4	2240
	NTS	2798.5	633.5	73.4	10.5	309.5	2351.2
	ORR	490.9	556.2	78.1	20.5	364.8	2232.5
	SRS	827.7	703.8	78.1	17.6	353.4	2286.6
Site 22	HAN	3609	1110.1	101	11.2	327.2	2157
	INL	3037.7	1020.5	89.1	11.6	330.6	2148.9
	NTS	3435.3	979.2	97.1	10.4	330	2176.7
	ORR	440.3	409.2	26.7	18	361.9	1977
	SRS	413.8	244.3	14.9	16.1	316.6	2122.8
Site 23	HAN	1463	286.6	59.9	8.9	338.7	2410.2
	INL	891.8	196.9	48	9.2	361.3	2457.8
Site 24	HAN	3432.6	1043.6	97.5	10.9	328.7	2172.2
	INL	2861.4	954	85.6	11.3	332.4	2165.8
	NTS	3259	912.8	93.5	10.1	331.8	2193.2
	ORR	264	342.7	23.1	18.8	373	2013.5
	SRS	280.3	243.7	15.4	17.2	314.6	2261.7
Site 25	HAN	3186.1	701.7	74.4	10.2	306.8	2221.5
	INL	2614.9	612	62.5	10.5	309.4	2222.1
	NTS	3012.4	570.8	70.4	9.3	306.8	2252.2
	SRS	296.1	274.9	36.9	19.3	356	2280.7
Site 26	HAN	936.9	365.8	94	12.1	370.1	2539.6
	INL	1190.6	251.3	90.7	8.5	385	2660.9
	NTS	877.6	175.3	85.6	8.6	378.5	2944.5
	ORR	3314.6	724.7	145	9.6	338.4	2498.1
	SRS	3478.9	942.1	184.7	10	351.4	2456.4
Site 27	HAN	3060.1	624.9	56	10.7	297.3	2225.7
	INL	2488.9	535.2	44.1	11.2	298.7	2227.8
	NTS	2880.7	576.8	74.3	10.5	311.9	2342.1
	ORR	332.5	287.3	33.5	20	336.3	2119.5
	SRS	623.3	453.8	35.7	17.4	335.3	2249.4
Site 28	HAN	362.6	118.1	34.5	9	409.3	2448.9
	INL	1018.7	237.3	41.2	9.8	348.4	2385.7
	NTS	1676.3	383.6	86	9.2	358.5	2438.3
	ORR	3399.4	789.7	100.5	10.2	320.2	2294.5
	SRS	3563.7	1016.1	140.1	10.5	336.1	2297.1
Site 29	HAN	3284.5	771.5	66.8	11.3	285.6	2251.2
	INL	2713.3	681.9	54.9	11.9	285.1	2258.4
	NTS	3105.1	723.5	85.1	11.2	296.4	2347.3
	ORR	746.2	470.2	22.7	18.5	294.3	2103.6
	SRS	782.1	575.6	37.3	17.6	312.7	2162.5
Site 30	HAN	916.1	338.6	65.4	11.9	359.1	2363.1
	INL	1145.3	209.7	56.3	8.1	365.9	2509.2
	NTS	886.7	188	88.4	9.1	360.6	2876.8
	ORR	3269.2	683.1	110.6	9.5	329.7	2370.3
	SRS	3433.6	900.6	150.3	9.8	345.3	2352.7
Site 31	HAN	309.5	44.9	20.4	6.3	417.8	2496

TABLE 3.1-1—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Truck Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density (/km^2)	Suburban Population Density (/km^2)	Urban Population Density (/km^2)
	INL	965.7	164.1	27.1	9	323.6	2388.3
	NTS	1623.3	310.4	71.9	8.7	347.8	2449.5
	ORR	3346.4	725.5	86.4	10	311.7	2280.4
	SRS	3510.7	942.9	126	10.3	330.8	2287.8
Site 32	HAN	2853.2	490.9	52.8	10.1	299.9	2317
	INL	2282	401.2	2724.3	10.4	302.3	2345.8
	NTS	2673.8	442.8	71.1	9.8	319.1	2415.1
	ORR	388.1	311.3	34.2	19.5	313	2199.8
	SRS	638.4	536.3	77.4	19.1	345.3	2365.2
Site 33	HAN	309.5	44.9	20.4	6.3	417.8	2496
	INL	965.7	164.1	27.1	9	323.6	2388.3
	NTS	1623.3	310.4	71.9	8.7	347.8	2449.5
	ORR	3346.4	725.5	86.4	10	311.7	2280.4
	SRS	3510.7	942.9	126	10.3	330.8	2287.8
Site 34	HAN	3445.3	999.2	95.2	11.7	302.9	2286.8
	INL	2874.1	909.5	83.3	12.3	304.2	2296.7
	NTS	3265.9	951.2	113.5	11.5	312	2353.1
	ORR	676.2	675	53.4	19.7	332.5	2198.6
	SRS	779.9	727.5	63.3	18.3	344.7	2234.2
Site 35	HAN	3536.4	1055.1	134	11.8	320.3	2420.7
	INL	2965.2	965.5	122.1	12.4	323.2	2440.4
	NTS	3357	1007.1	152.3	11.7	329.7	2454
	ORR	639.3	729.3	96.2	20.5	357.7	2464.6
	SRS	743	781.8	106.2	18.9	367.4	2460.9
Site 36	HAN	1739.3	459.6	102.5	9.3	356.8	2548.2
	INL	1168.1	369.9	90.6	9.7	373.2	2591.6
	NTS	435.3	178.9	43	8.5	381.4	2745.4
	ORR	2844.3	649.4	117.8	10.5	315.6	2525.2
	SRS	2763.4	854	119.7	11.6	322.1	2415.6
Site 37	HAN	939.8	373.2	83	12.1	368	2376.2
	INL	1193.5	258.7	79.6	8.5	381.7	2507.3
	NTS	870.4	166.6	74.1	8.5	370.6	2897.8
	ORR	3244	661.9	139.5	9.7	328.8	2596.8
	SRS	3408	877.2	178.2	10.1	344.9	2533.8
Site 38	HAN	2132.7	366.3	60.6	7.9	341.3	2314.4
	INL	1561.5	276.7	48.7	7.7	358.2	2338
	NTS	1305	129.1	18.2	6.8	322	2326.4
	ORR	1714.6	443	54.9	11.2	303.3	2247.7
	SRS	1878.6	658.4	93.6	11.7	333.2	2272
Site 39	HAN	3350.4	919.1	114.1	10.5	327.6	2250.1
	INL	2779.2	829.4	102.1	10.9	331.7	2253.8
	NTS	3176.4	786.1	109.1	9.7	330.8	2271.5
Site 40	HAN	3457.5	945	105.9	10.7	317.8	2249.5
	INL	2886.3	855.4	94	11.1	320.8	2253.5
	NTS	3283.5	812	101	9.9	319.3	2272.6
	ORR	403.2	300.9	28.7	18.2	322.8	2287.4
	SRS	251.9	172.7	8.5	14.2	320.7	2238.8
Site 41	HAN	243.4	109.4	20.7	11.3	332.2	2245.8
	INL	1020.8	239.3	27.5	10.1	306	2200.8

TABLE 3.1-1—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Truck Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density (/km^2)	Suburban Population Density (/km^2)	Urban Population Density (/km^2)
	NTS	1678.4	385.5	72.2	9.4	332.2	2378
	ORR	3395.2	774.2	80	10.8	311.4	2202.5
	SRS	3559.6	991.6	119.6	11.1	329.6	2236.1
Site 42	HAN	3196.5	810.2	86.3	11.2	297.6	2305.6
	INL	2625.3	720.5	74.4	11.8	298.7	2319.6
	NTS	3017.1	762.1	104.6	11.1	308.7	2374.2
	ORR	699.6	526.2	36.5	19	302.2	2237.1
	SRS	820.7	589.7	46.5	17.8	318.4	2277.4
Site 43	HAN	2964.2	523.4	85.8	9.1	341.5	2393
	INL	2393	433.7	73.9	9.3	352.4	2421.2
	NTS	2503.6	374.9	77.2	7.9	360.5	2435.2
	ORR	1151	419.4	48.9	15.2	315.5	2274.4
	SRS	1057.9	625.8	75.4	15.7	348.8	2261.2
Site 44	INL	2912.2	775.4	61.2	12.2	284.9	2277.2
Site 45	HAN	2203.6	524.5	108.1	9.2	345.6	2431.7
	INL	1632.3	434.9	96.2	9.4	357.3	2458.1
	NTS	899.6	243.8	48.6	8.5	350.7	2463.5
	ORR	2162.3	621.4	90.5	11.8	332.9	2324
	SRS	2242.2	752.9	87.8	12.3	320.8	2257.5
Site 46	HAN	1710.7	390.9	138.5	9.1	357.4	2731.4
	INL	1139.5	301.3	126.6	9.4	377.8	2779.6
	NTS	406.8	110.2	79	7.5	398.8	2976.5
	ORR	2780.3	605.5	144.5	9.8	330	2650.2
	SRS	2944.3	820.9	183.2	10.2	346.9	2577.6
Site 47	HAN	3518.7	1020.1	111.6	10.7	318.4	2263.4
	INL	2947.5	930.5	99.7	11.1	321.2	2268.8
	NTS	3425.1	786.2	115.2	9.9	334.3	2347.1
	ORR	464.4	376	34.4	17.6	323.5	2326.1
	SRS	475	291.9	23.7	16	310.1	2232.9
Site 48	HAN	2770.1	450.5	37.5	10	287.2	2241.6
	INL	2198.9	360.8	25.6	10.3	286.8	2252.6
	NTS	2590.7	402.4	55.7	9.7	306.9	2391.4
	ORR	455.9	325.4	32.7	19.2	320.3	2250.4
	SRS	758.4	474.9	54.3	17.1	316.4	2329.7
Site 49	HAN	3585.3	1098.6	108.9	11.9	307.8	2438.8
	INL	3014.1	1008.9	96.9	12.6	309.5	2465.9
	NTS	3405.9	1050.5	127.1	11.8	316.3	2476.1
	ORR	661	786.1	108	20.5	364.5	2576
	SRS	764.7	838.6	117.9	19	373.1	2563.2
Site 50	HAN	3378.5	910.1	98.9	11.7	301.2	2307.1
	INL	2807.3	820.4	87	12.3	302.5	2319.3
	NTS	3199.1	862	117.2	11.6	311.2	2368.2
	ORR	435.1	380	39.7	18.8	319.1	2308.8
	SRS	494.9	439.9	42.1	17.7	331.8	2341.6
Site 51	HAN	2904	622.8	56	10.5	297.2	2281.6
	INL	2332.8	533.2	44.1	10.9	298.6	2298.7
	NTS	2724.6	574.8	74.3	10.2	311.8	2384.1
	ORR	423.8	438.5	58	20.4	359.8	2216.2
	SRS	759.8	584.2	57.9	17.3	347.6	2289.8

TABLE 3.1-1—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Truck Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density (/km^2)	Suburban Population Density (/km^2)	Urban Population Density (/km^2)
Site 52	HAN	2566.7	390.9	49.4	8.4	320.2	2221.6
	INL	1995.5	301.2	37.5	8.4	329.5	2222.8
	NTS	2387.3	342.8	67.7	8	348	2350.5
	ORR	619.4	314.7	27.2	17.5	295.4	2286.4
	SRS	783.7	532.2	66.9	17.4	335.9	2296.7
Site 53	HAN	2753.4	522.9	64.8	9.1	332.1	2189.6
	INL	2182.3	433.3	52.9	9.3	341	2183.2
	NTS	2500.9	387.2	45.7	8.5	323	2255.6
	ORR	589.3	316	18.6	18.3	291.3	2149
	SRS	753.7	533.4	58.3	18.1	333.4	2254.2
Site 54	HAN	2132.7	366.3	60.6	7.9	341.3	2314.4
	INL	1561.5	276.7	48.7	7.7	358.2	2338
	NTS	1305	129.1	18.2	6.8	322	2326.4
	ORR	1714.6	443	54.9	11.2	303.3	2247.7
	SRS	1878.6	658.4	93.6	11.7	333.2	2272
Site 55	HAN	2918.5	562.8	84.2	9.4	337.7	2308.8
	INL	2347.3	473.2	72.3	9.6	347	2323.7
	NTS	2147.4	455.1	97.7	8	364.3	2428.8
	ORR	1087.8	479.1	70.6	15.8	337.7	2344.1
	SRS	1167.7	610.6	67.8	16.6	321.8	2258.9
Site 56	HAN	827.5	182.4	34.8	9.6	335.2	2377.4
	INL	256.3	92.8	22.9	11.7	380	2460.4
	NTS	633.5	111.1	35.8	8.2	365.4	2486.1
	ORR	2374.3	550.3	64.1	10.4	313.5	2240.7
	SRS	2538.7	767.8	103.8	10.8	336.4	2264.8
Site 57	HAN	3485.3	860.4	71.1	11.7	303.4	2234.1
	INL	2914.1	770.7	59.2	12.3	305.1	2237.4
	NTS	3305.9	812.3	89.4	11.5	314.2	2329.1
	ORR	344.5	278.8	9.5	19.2	293.7	1873.8
	SRS	448.2	331.3	19.5	17	326.6	2156.3
Site 58	HAN	2702.8	421.7	49.1	9.5	295.1	2336.6
	INL	2202	352.2	31.9	10.5	291.6	2462.3
	NTS	2593.8	393.8	62.1	9.8	311.7	2485
	ORR	638	453.7	76.5	19.2	344.5	2406.3
	SRS	888.4	678.7	119.6	19	359.6	2438.8
Site 59	HAN	467.1	93.8	10.5	8.9	299.4	2116.4
	INL	883.1	140	16.4	7.8	324.7	2211.9
	NTS	1656.7	329.8	64.4	8.7	346.7	2395.2
	ORR	3128.7	708.3	68	10.9	312.9	2187.1
	SRS	3293	925.7	107.7	11.2	332.1	2230.1
Site 60	HAN	3222.7	803.7	75.2	11.3	290.5	2271.9
	INL	2651.5	714	63.3	11.9	290.7	2282.1
	NTS	3043.3	755.6	93.5	11.2	301.2	2355.3
	ORR	725.7	519.7	25.4	19.1	291.3	2107.7
	SRS	846.9	583.2	35.4	17.9	308.8	2197.1
Site 61	HAN	3572.4	1054.3	104.0	11.9	305.5	2391.8
	INL	3001.2	964.6	92.1	12.5	307.1	2414.2
	NTS	3393	1006.2	122.2	11.7	314.3	2437.6
	ORR	648.1	741.7	103.1	20.4	364.7	2535.1

TABLE 3.1-1—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Truck Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density ($/km^2$)	Suburban Population Density ($/km^2$)	Urban Population Density ($/km^2$)
	SRS	751.8	794.2	113.0	18.9	373.8	2525.4
				Rural	**Suburban**	**Urban**	**Total**
	Percentage within Population Zone			75.2	21.7	3.0	
	Average Population Density ($/km^2$)			11.1	323.7	2372.0	

1. Source: DOE 1995d and original calculations.

TABLE 3.1-2—*Route Characteristics Used to Develop Domestic Programmatic Inputs[1]—Rail Option*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density ($/km^2$)	Suburban Population Density ($/km^2$)	Urban Population Density ($/km^2$)
Site 1	HAN	3429.4	762.4	178.8	8.0	382.9	2406.6
	INL	2849.5	668.7	165.3	10.1	379.2	2426.9
	NTS	3136.2	711.3	179.8	9.3	381.0	2418.9
	ORR	872.4	473.0	106.3	17.9	382.7	2458.0
	SRS	1007.3	691.2	219.7	13.6	432.3	2717.9
Site 2	HAN	2748.4	413.6	79.2	5.7	359.4	2320.1
	INL	2168.6	319.9	65.6	8.0	344.8	2353.3
	NTS	2455.2	362.4	80.2	7.2	352.3	2348.8
	ORR	692.0	302.3	68.7	16.4	365.2	2397.7
	SRS	969.9	477.3	110.4	13.7	424.6	2274.4
Site 3	HAN	3595.4	727.1	156.9	7.5	382.4	2335.6
	INL	3021.3	630.7	142.1	9.5	377.4	2356.0
	NTS	3307.7	673.2	156.3	8.8	379.5	2353.3
	ORR	300.2	259.1	25.7	19.1	400.0	2100.6
	SRS	451.8	273.0	38.4	12.2	465.4	2051.0
Site 4	HAN	3465.8	968.1	373.9	8.2	411.6	2719.5
	INL	2886.9	872.0	356.5	10.5	410.3	2737.6
	NTS	3173.5	914.6	371.0	9.6	410.2	2721.6
	ORR	575.4	526.7	237.5	17.0	440.9	2916.2
	SRS	763.7	520.5	231.9	12.2	459.7	2894.5
Site 5	HAN	3801.2	920.2	196.0	7.8	399.0	2292.2
	INL	3171.4	682.1	132.2	8.6	423.4	2194.4
	NTS	3457.8	724.5	146.4	8.0	422.6	2207.2
	ORR	543.0	275.4	51.0	14.8	423.9	2236.3
	SRS	189.2	39.3	5.5	6.0	443.6	2109.3
Site 6	HAN	3357.0	800.1	220.9	7.7	391.8	2530.4
	INL	2783.8	701.9	202.3	9.9	386.6	2549.8
	NTS	3070.2	744.3	216.4	9.1	387.9	2535.3
	ORR	900.1	445.4	105.1	16.3	392.0	2463.6
	SRS	998.9	533.1	93.3	14.2	423.9	2306.0
Site 7	HAN	1779.9	173.1	33.2	5.5	394.6	2236.7
	INL	1051.9	89.7	19.2	4.6	408.5	2269.2
	NTS	1192.9	96.6	15.9	4.9	378.2	2234.3
	ORR	1816.8	436.5	62.5	10.4	382.7	2222.3
	SRS	2088.0	642.5	113.7	10.2	410.2	2194.9

TABLE 3.1-2—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Rail Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density (/km^2)	Suburban Population Density (/km^2)	Urban Population Density (/km^2)
Site 8	HAN	1755.0	152.3	27.2	5.3	400.3	2241.0
	INL	1027.0	68.9	13.2	4.1	425.2	2293.0
	NTS	1247.7	119.7	22.3	5.5	362.7	2352.2
	ORR	1871.0	463.4	69.5	10.6	381.3	2248.9
	SRS	2142.2	669.4	120.8	10.3	408.2	2211.8
Site 9	HAN	3530.6	741.1	193.3	7.7	387.1	2446.6
	INL	2956.5	644.7	178.5	9.8	382.8	2472.1
	NTS	3242.9	687.2	192.6	9.0	384.5	2461.4
	ORR	471.1	341.4	59.8	17.2	401.7	2436.1
	SRS	659.4	335.2	54.2	11.6	430.0	2293.6
Site 10	HAN	3163.8	476.3	95.7	6.5	422.4	2291.4
	INL	2435.9	392.8	81.7	6.4	431.5	2308.5
	NTS	2577.6	395.6	78.4	6.5	421.5	2328.4
	ORR	1025.2	527.3	82.9	14.5	388.2	2308.9
	SRS	1146.0	578.1	110.9	12.7	426.9	2283.4
Site 11	HAN	3454.3	785.3	161.2	7.5	387.8	2293.9
	INL	2824.4	547.2	97.4	8.3	413.3	2162.2
	NTS	3110.9	589.6	111.6	7.6	413.1	2183.1
	ORR	196.0	140.5	16.2	21.5	385.3	2132.8
	SRS	250.0	95.6	29.3	10.8	472.5	2317.3
Site 12	HAN	3682.6	862.1	232.1	8.1	397.4	2465.8
	INL	3108.5	765.7	217.4	10.2	395.1	2488.0
	NTS	3394.9	808.1	231.5	9.4	395.9	2478.1
	ORR	516.6	369.2	44.8	18.4	395.0	2150.5
	SRS	625.2	300.0	38.3	11.7	411.3	2080.2
Site 13	INL	935.8	106.4	20.1	6.9	400.0	2235.0
Site 14	HAN	257.0	25.1	7.9	4.0	419.5	2426.8
	INL	1142.7	101.0	17.4	6.4	391.3	2293.6
	NTS	1730.8	171.3	37.0	6.0	385.0	2317.9
	ORR	3331.7	694.9	144.2	7.9	364.3	2374.2
	SRS	3616.7	866.7	185.1	7.9	395.5	2313.3
Site 15	HAN	2549.8	268.5	41.5	6.7	373.6	2182.2
	INL	1821.8	185.1	27.5	6.6	370.9	2177.1
	NTS	2108.3	227.5	41.7	5.8	378.1	2228.0
	ORR	1023.4	427.6	107.3	15.9	354.1	2425.9
	SRS	1308.4	599.4	148.2	14.0	402.1	2335.6
Site 16	HAN	2554.2	214.8	34.3	6.0	400.4	2137.8
	INL	1826.2	131.3	20.3	5.7	413.6	2100.5
	NTS	1931.3	158.7	23.8	5.0	376.2	2245.7
	ORR	1079.0	372.1	54.4	14.1	381.6	2238.8
	SRS	1350.1	578.1	105.6	13.0	412.6	2201.2
Site 17	HAN	2318.3	275.5	55.3	5.7	409.4	2258.6
	INL	1590.4	192.0	41.3	5.2	422.4	2281.2
	NTS	1639.7	112.5	20.7	4.4	368.9	2533.7
	ORR	2224.8	487.2	61.5	9.5	404.7	2138.7
	SRS	2434.8	607.7	89.1	9.9	411.8	2193.4
Site 18	HAN	3671.2	878.0	229.3	8.1	382.2	2613.1
	INL	3097.2	781.6	214.5	10.2	378.2	2645.8

TABLE 3.1-2—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Rail Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density (/km^2)	Suburban Population Density (/km^2)	Urban Population Density (/km^2)
	NTS	3383.6	824.1	228.7	9.4	379.8	2626.1
	ORR	567.8	497.8	208.1	17.1	431.8	2982.4
	SRS	756.1	491.6	202.5	12.2	451.5	2959.3
Site 19	HAN	3673.8	959.4	233.8	8.4	386.4	2496.1
	INL	3099.7	863.0	219.0	10.5	383.1	2520.2
	NTS	3386.1	905.4	233.2	9.7	384.4	2508.5
	ORR	1161.1	670.2	160.5	17.1	389.3	2572.9
	SRS	993.1	693.6	248.9	12.7	444.2	2767.5
Site 20	HAN	1125.9	106.7	17.4	4.3	378.9	2250.9
	INL	1250.8	154.3	37.5	5.9	370.9	2455.2
	NTS	846.0	223.9	96.1	7.7	405.3	2711.7
	ORR	3500.4	572.5	98.4	7.8	384.8	2293.9
	SRS	3771.6	778.5	149.6	7.8	407.0	2248.5
Site 21	HAN	3025.6	583.6	133.3	6.9	381.9	2349.1
	INL	2451.5	487.2	118.5	9.1	375.3	2375.3
	NTS	2737.9	529.7	132.7	8.3	378.1	2370.1
	ORR	588.8	361.9	70.9	17.4	394.1	2266.8
	SRS	1064.0	477.2	67.5	16.1	379.5	2171.6
Site 22	HAN	3940.9	917.3	154.3	8.9	371.0	2296.1
	INL	3293.2	781.5	104.7	9.7	411.8	2152.4
	NTS	3579.6	823.9	118.8	9.0	411.7	2173.2
	ORR	492.7	357.4	31.2	16.2	429.1	1988.5
	SRS	464.0	146.1	11.8	11.0	396.0	1919.5
Site 23	HAN	1523.7	176.8	40.0	6.4	390.3	2287.5
	INL	796.1	93.4	25.7	5.9	399.7	2332.1
Site 24	HAN	3845.1	839.7	128.0	8.9	413.8	2200.6
	INL	3117.4	756.3	113.7	9.4	417.5	2199.8
	NTS	3403.8	798.7	127.8	8.7	417.1	2213.9
	ORR	317.0	332.2	40.2	16.8	443.5	2159.2
	SRS	439.1	177.4	19.8	12.0	407.1	2134.2
Site 25	HAN	3426.2	706.1	149.2	7.8	364.4	2353.7
	INL	2803.3	436.8	75.5	8.5	400.3	2223.0
	NTS	3089.7	479.2	89.6	7.8	401.1	2239.4
	SRS	446.1	236.1	45.5	15.5	420.6	2251.5
Site 26	HAN	1198.5	149.2	47.0	4.7	386.6	2735.5
	INL	1323.5	196.8	67.1	6.2	378.5	2704.6
	NTS	874.2	246.1	99.7	7.5	402.7	2775.9
	ORR	3573.1	615.0	128.0	7.9	386.3	2462.0
	SRS	3895.6	821.5	161.4	9.1	400.1	2407.1
Site 27	HAN	3095.6	536.6	125.6	6.7	377.6	2353.1
	INL	2521.5	440.2	110.8	8.9	369.4	2381.6
	NTS	2808.0	482.6	124.9	8.1	373.0	2375.4
	ORR	419.0	172.2	34.6	16.1	366.1	2505.3
	SRS	833.9	303.5	23.6	15.4	339.9	2043.7
Site 28	HAN	373.9	127.0	37.3	8.5	415.2	2326.1
	INL	1169.6	183.2	54.8	7.9	429.4	2380.2
	NTS	1572.0	383.1	128.8	7.7	405.7	2626.8
	ORR	3719.8	625.2	120.3	8.6	399.5	2285.4
	SRS	3991.0	831.2	171.6	8.6	416.6	2248.4

TABLE 3.1-2—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Rail Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density ($/km^2$)	Suburban Population Density ($/km^2$)	Urban Population Density ($/km^2$)
Site 29	HAN	3198.7	782.7	234.3	7.5	395.6	2567.1
	INL	2625.5	683.9	215.7	9.8	390.8	2588.5
	NTS	2911.9	726.3	229.8	9.0	391.9	2572.4
	ORR	750.2	423.2	96.4	17.6	389.3	2438.0
	SRS	946.5	449.3	69.5	14.3	418.1	2221.9
Site 30	HAN	1075.7	207.0	53.3	7.0	377.3	2533.3
	INL	1307.4	192.7	62.9	6.5	372.5	2537.7
	NTS	835.9	202.4	69.5	7.2	390.0	2725.3
	ORR	3557.0	610.9	123.8	8.0	384.4	2368.9
	SRS	3766.7	835.8	153.9	9.0	400.3	2394.3
Site 31	HAN	318.7	63.0	12.3	5.2	371.5	2263.1
	INL	1113.2	119.0	30.7	6.9	417.8	2391.5
	NTS	1701.3	189.2	50.2	6.4	402.2	2371.2
	ORR	3663.5	561.1	96.2	8.3	393.6	2265.2
	SRS	3934.6	767.0	147.5	8.3	413.7	2229.1
Site 32	HAN	2851.3	467.9	106.5	5.9	373.1	2372.0
	INL	2450.2	240.2	41.2	6.5	410.0	2141.5
	NTS	2736.6	282.6	55.4	6.0	409.9	2188.8
	ORR	493.4	217.0	45.9	16.0	375.9	2469.1
	SRS	897.0	420.9	84.5	14.0	422.8	2209.7
Site 33	HAN	318.7	63.0	12.3	5.2	371.5	2263.1
	INL	1113.2	119.0	30.7	6.9	417.8	2391.5
	NTS	1701.3	189.2	50.2	6.4	402.2	2371.2
	ORR	3663.5	561.1	96.2	8.3	393.6	2265.2
	SRS	3934.6	767.0	147.5	8.3	413.7	2229.1
Site 34	HAN	3536.6	839.4	188.0	8.1	380.9	2409.8
	INL	2962.5	743.0	173.2	10.3	376.4	2432.8
	NTS	3249.0	785.4	187.4	9.5	378.2	2424.8
	ORR	978.9	550.2	114.7	17.4	381.5	2461.9
	SRS	856.1	574.7	203.2	12.4	448.1	2748.7
Site 35	HAN	3679.2	966.4	229.3	8.4	385.2	2501.9
	INL	3099.4	872.7	215.8	10.5	382.6	2523.4
	NTS	3386.0	915.3	230.3	9.7	383.8	2511.1
	ORR	1115.4	680.0	157.3	17.2	388.5	2578.3
	SRS	992.3	703.3	245.7	12.8	442.7	2773.5
Site 36	HAN	1404.4	494.3	239.5	9.0	419.3	2786.9
	INL	1401.1	243.0	128.5	5.3	442.7	2670.0
	NTS	605.0	149.6	102.7	4.6	469.5	2754.6
	ORR	3325.9	662.5	159.6	8.3	411.8	2495.6
	SRS	3329.7	901.8	269.6	8.6	425.0	2502.7
Site 37	HAN	1075.7	207.0	53.3	7.0	377.3	2533.3
	INL	1307.4	192.7	62.9	6.5	372.5	2537.7
	NTS	835.9	202.4	69.5	7.2	390.0	2725.3
	ORR	3557.0	610.9	123.8	8.0	384.4	2368.9
	SRS	3766.7	835.8	153.9	9.0	400.3	2394.3
Site 38	HAN	2420.3	295.1	60.9	5.7	416.5	2278.8
	INL	1692.4	211.7	46.9	5.2	431.1	2304.7
	NTS	1567.9	94.9	15.1	4.3	340.2	2555.5
	ORR	2153.1	469.6	55.9	9.6	400.3	2104.6

TABLE 3.1-2—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Rail Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density (/km^2)	Suburban Population Density (/km^2)	Urban Population Density (/km^2)
	SRS	2363.0	590.1	83.4	10.0	408.5	2174.3
Site 39	HAN	3704.3	880.9	190.5	7.7	397.0	2297.5
	INL	3074.5	642.8	126.7	8.5	422.1	2198.1
	NTS	3360.9	685.2	140.9	7.9	421.4	2211.0
Site 40	HAN	3779.2	906.4	192.9	7.9	397.4	2295.1
	INL	3149.3	668.3	129.1	8.6	421.8	2196.4
	NTS	3435.8	710.7	143.2	8.0	421.0	2209.3
	ORR	520.9	261.7	47.9	15.3	419.8	2244.3
	SRS	167.1	25.5	2.3	6.1	412.1	2105.4
Site 41	HAN	293.4	100.9	23.3	7.7	384.8	2359.5
	INL	1260.5	217.3	39.6	8.2	381.3	2321.4
	NTS	1838.4	272.8	57.2	6.9	385.9	2328.7
	ORR	3631.6	806.7	169.2	7.8	369.2	2386.9
	SRS	3916.7	978.5	210.1	7.8	396.0	2330.8
Site 42	HAN	3251.3	659.2	164.9	7.2	387.2	2418.9
	INL	2677.2	562.8	150.1	9.3	3382.4	2446.5
	NTS	2963.6	605.2	164.2	8.5	384.3	2436.2
	ORR	693.6	370.0	91.6	16.7	393.0	2491.6
	SRS	1105.6	495.8	92.2	15.8	381.9	2408.5
Site 43	HAN	3079.3	426.5	76.6	6.4	418.8	2225.4
	INL	2351.4	343.0	62.6	6.3	428.3	2232.9
	NTS	2492.4	344.0	58.1	6.4	417.6	2231.2
	ORR	1234.9	373.6	39.9	11.9	400.9	2131.4
	SRS	1251.0	545.7	100.1	12.6	418.2	2325.7
Site 44	INL	2773.1	732.4	227.1	10.1	388.6	2584.4
Site 45	HAN	1975.8	530.4	155.6	8.9	376.5	2593.0
	INL	1922.5	273.6	70.8	6.1	363.0	2458.2
	NTS	1126.4	180.2	45.0	6.3	344.0	2530.3
	ORR	2344.4	567.5	92.6	9.2	408.1	2241.1
	SRS	2727.2	670.0	155.0	8.4	429.2	2374.2
Site 46	HAN	1371.6	428.1	189.9	8.8	411.1	2794.2
	INL	1368.2	176.9	78.9	5.1	431.6	2614.2
	NTS	572.2	83.5	53.2	4.0	467.3	2750.6
	ORR	3293.1	596.3	110.0	8.2	405.1	2377.1
	SRS	3296.8	835.7	220.0	8.5	421.1	2445.0
Site 47	HAN	3858.4	603.9	80.1	8.5	395.3	2151.1
	INL	3105.0	520.3	65.8	8.9	397.9	2139.0
	NTS	3391.5	562.7	80.0	8.3	398.8	2172.2
	ORR	629.6	310.0	36.9	17.1	406.4	2116.6
	SRS	538.2	132.8	7.7	8.4	388.2	2284.8
Site 48	HAN	2846.9	472.9	111.7	6.0	380.4	2335.0
	INL	2364.2	227.7	41.0	6.4	409.7	2176.7
	NTS	2650.6	270.1	55.2	5.8	409.7	2215.2
	ORR	620.5	232.0	49.6	15.2	381.5	2403.0
	SRS	895.3	427.6	88.8	13.8	423.6	2207.8
Site 49	HAN	3676.9	927.6	206.5	8.4	384.7	2432.6
	INL	3102.8	831.2	191.7	10.4	381.2	2455.3
	NTS	3389.2	873.7	205.8	9.7	382.5	2446.4
	ORR	1119.2	638.5	133.2	17.0	387.0	2490.2

TABLE 3.1-2—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Rail Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density (/km^2)	Suburban Population Density (/km^2)	Urban Population Density (/km^2)
	SRS	1005.5	698.8	229.6	12.8	442.1	2750.4
Site 50	HAN	3530.6	741.1	193.3	7.7	387.1	2446.6
	INL	2956.5	644.7	178.5	9.8	382.8	2472.1
	NTS	3242.9	687.2	192.6	9.0	384.5	2461.4
	ORR	471.1	341.4	59.8	17.2	401.7	2436.1
	SRS	659.4	335.2	54.2	11.6	430.0	2293.6
Site 51	HAN	3011.1	564.9	165.9	6.6	386.4	2565.3
	INL	2437.9	466.1	147.3	8.8	377.4	2596.3
	NTS	2724.3	508.6	161.5	8.0	380.1	2572.7
	ORR	529.8	293.2	57.7	17.0	380.4	2330.7
	SRS	1005.0	408.4	54.3	15.8	367.2	2216.5
Site 52	HAN	2795.5	267.5	40.0	6.5	392.5	2138.6
	INL	2067.5	184.1	26.0	6.3	398.3	2109.9
	NTS	2354.0	226.5	40.2	5.7	400.4	2186.3
	ORR	732.3	305.7	48.5	16.4	396.5	2273.3
	SRS	1003.5	511.7	99.8	14.3	425.4	2215.8
Site 53	HAN	3030.7	349.3	70.1	6.9	403.4	2223.5
	INL	2302.7	265.8	56.1	6.9	410.8	2231.3
	NTS	2589.2	308.2	70.3	6.2	410.7	2250.6
	ORR	692.7	268.4	45.1	16.8	384.8	2226.8
	SRS	963.8	474.3	96.3	14.5	421.2	2192.0
Site 54	HAN	2420.3	295.1	60.9	5.7	416.5	2278.8
	INL	1692.4	211.7	46.9	5.2	431.1	2304.7
	NTS	1567.9	94.9	15.1	4.3	340.2	2555.5
	ORR	2153.1	469.6	55.9	9.6	400.3	2104.6
	SRS	2363.0	590.1	83.4	10.0	408.5	2174.3
Site 55	HAN	3039.4	413.1	77.9	6.4	415.3	2305.8
	INL	2311.5	329.6	63.9	6.2	424.3	2330.7
	NTS	2453.2	332.4	60.6	6.3	412.5	2357.7
	ORR	1306.6	443.1	76.4	12.1	419.6	2290.3
	SRS	1331.6	612.4	126.4	12.6	430.6	2277.9
Site 56	HAN	1034.3	212.2	48.4	8.2	390.7	2351.4
	INL	306.4	128.8	34.4	11.4	397.8	2416.3
	NTS	456.7	11.9	0.7	4.3	341.1	2605.4
	ORR	2555.4	543.0	94.5	9.1	392.9	2273.1
	SRS	2826.6	749.0	145.8	9.1	413.7	2233.8
Site 57	HAN	3587.2	746.3	161.5	7.6	383.2	2343.2
	INL	3013.1	649.9	146.8	9.6	378.5	2363.7
	NTS	3299.5	692.4	160.9	8.9	380.4	2360.5
	ORR	374.0	277.4	28.8	18.1	393.4	2163.7
	SRS	525.5	291.2	41.5	12.4	455.1	2098.6
Site 58	HAN	2513.8	415.8	60.7	6.4	334.4	2373.6
	INL	2370.0	296.4	40.6	8.0	327.7	2254.0
	NTS	2656.4	338.8	54.8	7.2	337.9	2272.8
	ORR	860.9	404.0	123.5	16.2	391.8	2726.6
	SRS	1148.5	592.6	157.8	14.0	431.6	2360.4
Site 59	HAN	325.7	34.4	9.8	6.5	369.5	2370.5
	INL	1131.8	97.6	16.4	6.3	391.5	2264.2
	NTS	1719.9	167.9	36.0	6.0	385.0	2305.2

TABLE 3.1-2—*Route Characteristics Used to Develop Domestic Programmatic Inputs—Rail Option (continued)*

Origin	Destination	Rural Distance (km)	Suburban Distance (km)	Urban Distance (km)	Rural Population Density (/km^2)	Suburban Population Density (/km^2)	Urban Population Density (/km^2)
	ORR	3320.9	691.5	143.1	7.9	364.2	2371.4
	SRS	3605.9	863.3	184.0	7.8	395.5	2310.8
Site 60	HAN	3315.7	682.6	167.7	7.3	389.8	2416.3
	INL	2741.6	586.2	152.9	9.4	385.6	2443.1
	NTS	3028.0	628.7	167.1	8.7	387.2	2433.2
	ORR	758.0	393.5	94.4	16.5	397.2	2484.8
	SRS	1170.0	519.3	95.1	15.7	385.6	2404.2
Site 61	HAN	3664.0	924.7	204.4	8.3	381.2	2433.1
	INL	3089.9	828.3	189.6	10.4	377.2	2456.0
	NTS	3376.6	870.8	203.7	9.7	378.8	2447.0
	ORR	1106.3	635.6	131.1	17.1	381.9	2491.8
	SRS	983.3	658.9	219.5	12.6	440.0	2745.2
				Rural	**Suburban**	**Urban**	**Total**
		Percentage within Population Zone		78.1	17.8	4.1	
		Average Population Density (/km^2)		8.65	409.8	2435.7	

1. Source: DOE 1995d and original calculations.

TABLE 3.1 -3—*Summary of Routing Inputs for Generic Domestic Programmatic Alternatives Analysis*

Route Distance (miles [km])	Distance within Population Zone (miles [km])			Population Density (/mi^2 [/km^2])		
	Rural	Suburban	Urban	Rural	Suburban	Urban
Legal Weight Truck Option						
150 (241)	109.6(176.4)	38.5 (62.0)	1.9 (3.1)	28.7 (11.1)	838.4 (323.7)	6,143.5 (2,372.0)
500 (805)	365.3 (587.9)	128.3 (206.5)	6.4 (10.3)	28.7 (11.1)	838.4 (323.7)	6,143.5 (2,372.0)
1,500 (2414)	1,096 (1764)	385 (619.6)	19 (30.6)	28.7 (11.1)	838.4 (323.7)	6,143.5 (2,372.0)
2,100 (3380)	1,534 (2469)	539 (867.4)	27 (43.5)	28.7 (11.1)	838.4 (323.7)	6,143.5 (2,372.0)
3,000 (4828)	2,192 (3528)	770 (1239)	38 (61.2)	28.7 (11.1)	838.4 (323.7)	6,143.5 (2,372.0)
Rail Option						
150 (241)	114.9 (184.9)	32.9(52.9)	2.2(3.5)	22.4 (8.65)	1,061.4 (409.8)	6,308.4 (2,435.7)
500 (805)	383(616.4)	109.7 (176.5)	7.3(11.8)	22.4 (8.65)	1,061.4 (409.8)	6,308.4 (2,435.7)
1,500 (2414)	1,149(1,849)	329(529.5)	22(35.4)	22.4 (8.65)	1,061.4 (409.8)	6,308.4 (2,435.7)
2,100 (3379)	1,609(2,589)	460.6(741.2)	30.4(48.9)	22.4 (8.65)	1,061.4 (409.8)	6,308.4 (2,435.7)
3,000 (4827)	2,298(3,698)	658(1059)	44.0(70.8)	22.4 (8.65)	1,061.4 (409.8)	6,308.4 (2,435.7)

Note: Due to rounding of values, the sum of the parts may not equal the total represented in the leftmost column

4. RADIONUCLIDE INVENTORIES AND SHIPMENT CONFIGURATIONS

For this PEIS analysis, nuclide inventories for commercial LWR spent fuel were based on the *AFCF Conceptual Design and NEPA Support Activities NEPA Data Study* (WGI 2007a), also known as the AFCF NEPA Data Study. It was assumed that the spent fuel transported would consist of fuel with a burnup of 100 GWD/MTU, with a minimum of five years cooling. The end-of-life effective enrichment, defined as the percentage of fissile material remaining in the heavy metal, is approximately 2.6 percent. The nuclide inventory is provided in Appendix 2 of the AFCF NEPA Data Study (WGI 2008a).

The exact composition and physical attributes of the spent fuel from each programmatic alternative has not yet been identified. For the Thermal/Fast Recycle Alternative, spent fuel and other material inventories were assumed to be the same used in the AFCF transportation analysis. For the remaining programmatic alternatives, spent fuel from each alternative has been assigned nuclide inventories from *Source Term Estimates for DOE SNF* (DOE 2004j). In this report, DOE spent fuel was organized into 34 groups based on fuel enrichment, fuel cladding material, and fuel cladding condition. The characteristics of the spent fuel, including percent enrichment, decay time, and burnup, would affect the radionuclide inventory and thereby radiation dose. A general sensitivity analysis of burnup and cooling times is provided in Chapter 4. Table 4-1 provides the per truck cask nuclide inventory of the fuel groups used to represent the spent fuel generated in the programmatic alternatives, including LWR and fast reactor spent fuels provided from the AFCF NEPA Data Study. The fuel groups chosen best represent the reactor types and enrichment requirements associated with the domestic programmatic alternatives. The following are descriptions of the fuel groups represented in Table 4-1:

Group 2: Uranium Metal, Non-Zirconium Alloy Clad, Low-Enriched Uranium. This group contains uranium metal fuel compounds with no known zirconium alloy cladding. The end-of-life effective enrichment ranges to 0.2 to 3.4 percent. The cladding is in good to poor condition.

Group 19: Thorium/Uranium Carbide, TRISO or BISO-Coated Particles in Graphite. This group contains thorium/uranium carbide fuel compounds with TRISO (tristructural isotopic) or BISO (bistructural isotopic)-coated particles. TRISO-coated particles consist of an isotropic pyrocarbon outer layer, a silicon carbide layer, an isotropic carbon layer, and a porous carbon buffer inner layer. BISO-coated particles consist of an isotropic pyrocarbon outer layer and a low density porous carbon buffer inner layer. The end-of-life effective enrichment ranges from 71.4 to 84.4. The coating is in good condition.

Group 23: Mixed Oxide, Stainless-Steel Clad. This group contains plutonium/uranium and plutonium oxide fuel compounds with stainless steel cladding. The end-of-life enrichment ranges from 2.1 to 87.4 percent. The cladding is in good condition.

Group 26: Thorium/Uranium, Stainless-Steel Clad. This group contains thorium/uranium oxide fuel compounds with stainless-steel cladding. The end-of-life enrichment ranges from 7.6 to 97.8 percent. The cladding is in good to fair condition.

The spent fuel from the fast recycling reactors is assumed to have a burnup of 250 GWD/MT, with a one-year cooling period. As with the LWR spent fuel, the end-of-life effective enrichment is approximately 2.6 percent. The nuclide inventory is provided in Appendix A-3 of the AFCF NEPA Data Study. Nuclide inventories of other materials and wastes analyzed are provided in Section 3 of the AFCF NEPA Data Study (WGI 2008a).

PWR assemblies were assumed to contain 0.5 MTHM spent fuel material, and BWR assemblies 0.2 MTHM spent fuel. For truck shipments, the GA-4/9 cask was modeled for transport of spent fuel. This cask can hold four PWR assemblies or nine BWR assemblies, yielding approximately two MTHM spent fuel per shipment. Rail LWR spent fuel shipments were analyzed using NLI-10/24 casks, which can hold 10 PWR or 24 BWR assemblies, yielding approximately five MTHM per cask. Each train was assumed to be comprised of five rail cask cars; so that approximately 25 MTHM spent fuel was transported in each rail shipment.

Each DOE rail cask is assumed to hold nine DOE spent fuel canisters. Therefore, each rail cask is assumed to hold the equivalent of nine truck shipments. With five rail cars per shipment, each rail shipment is assumed to transport the equivalent of 45 truck shipments of this material. It should be also noted that other spent fuel casks may be used for the transportation of the spent fuels analyzed in this PEIS. The DOE spent fuel canisters and casks were assumed due to the availability of information regarding these containers. As with most shipping configurations, transportation by rail provides for larger per-shipment capacity due to larger weight limits, which provides for greater cargo capacity, including added the added weight of shielding for greater thermal and radioactivity loads.

Shipment of fresh fuels was assumed to be conducted by truck transport, in accordance with 10 CFR 51.52. In the *Environmental Impact Statement for an Early Site Permit (ESP) at the Exelon ESP Site* (NRC 2006c), it was assumed that AP1000 (advanced PWR) fuel assemblies would have a mass of 0.583 MTHM. For the GNEP PEIS, it was assumed that PWR fuel assemblies would have a mass of 05 MTHM, which is bounded by the AP1000 assumption. 12 assemblies x 0.5 MTHM/assembly = 6 MTHM.

Based on data provided in Chapter 1 of the GNEP PEIS, the initial enrichment is 12.2-19.9%, or 2.8-4.5 times higher than the 4.4% assumed for LEU fuel. Assuming an average scaling factor of 3.65, compared to LWR fuel, there would be 6 MTHM/3.65 = 1.7 MTHM/shipment.

As provided in the *AFCF NEPA Data Study* (WGI 2008a), shipment of transmutation fuel will utilize modified GA-4/9 casks to transport 2 LTAs per cask, or 0.4 MTHM per shipment. The nuclide inventory for the ceramic oxide form is based upon generation data provided in Table 25 of the WGI report. Table 4-1 provides the per shipment inventory for this fuel.

The Environmental Impact Statement on the Construction and Operation of a Mixed Fuel Fabrication Facility at the Savannah River Site, South Carolina (MOX Fuel Fabrication Facility EIS) (NRC 2005c) assumes that fresh MOX fuel will be transported in NRC Type B containers. Three assemblies per container will be transported. The per-shipment nuclide inventory was based on Table C.3 of the MOX Fuel Fabrication Facility EIS, and is provided in Table 4-1 of this document. Based on the values provided in the MOX Fuel Fabrication Facility EIS, each shipment assumes 1.37 MTHM of fresh fuel.

NRC 2006c states that each fuel assembly contains 18 kg of uranium. Each shipment could hold 180 to 240 assemblies per shipment. For sake of conservativeness, the lower shipment quantity was assumed. 18 kg U/assembly x 240 assemblies/shipment = 3240 kg U/shipment = 3.24 MTHM/shipment.

In NRC 2006c each spent GT-MHR fuel shipment was assumed to hold 6 assemblies for a total of 0.023 MTHM. This translates to 0.00383 MTHM/assembly. Also stated in NRC 2006c, each truck shipment of fresh fuel would be comprised of 80 assemblies. 0.00383 MTHM/assembly x 80 assemblies/shipment = 0.307 MTHM/shipment.

Nuclide inventories for non-spent fuel materials and wastes were provided by WGI 2008a. Waste generation values for separation and fuel fabrication processes were provided in WGI 2008a and WGI 2008c for programmatic alternatives. Per-container alternatives were derived by applying packaging assumptions provided in the section below. The source documents for nuclide inventories are provided in Folder 3 – Shipments and Containers..

TABLE 4-1—*Truck Cask Nuclide Inventories of Nuclear Fuels* [a]

Nuclide	LWR SNF[b,c]	Fast Reactor SNF[b,c]	Fresh Transmutation Fuel[b]	Fresh MOX Fuel	Thorium Cycle Fuel (Group 26)	Thermal Recycle Fuel (Group 23)	HWR SNF (Group 2)	HTGR SNF (Group 19)
Ac-227	8.8×10^{-4}	2.5×10^{-7}			7.4	0.042	5.8×10^{-4}	2.6
Am-241	4.2×10^{4}	27	8.4×10^{-9}		7,100	2.5×10^{5}	2.1×10^{4}	2,300
Am-242m	220	530	8.7×10^{4}		16	2,100	34	2.2
Am-243	720	140	1,500		15	440	6.4	40
C-14	17	0.12			1.2	8,300	2,000	20
Cl-36					2.2	49	37	0.92
Cm-243	520	160	1,100		1.0	580	6.6	30
Cm-244	1.9×10^{5}	3.1×10^{4}	3.9×10^{5}		220	7,700	89	9,000
Co-60	4.4×10^{4}	50			9.5×10^{4}	3.5×10^{6}	4.6×10^{5}	2,300
Cs-134	3.0×10^{5}	1.7×10^{4}			11	4.1×10^{4}	150	3,700
Cs-135	12	0.48			2.6	49	1.9	21
Cs-137	1.4×10^{6}	2.9×10^{4}			1.4×10^{5}	2.3×10^{6}	2.2×10^{5}	1.5×10^{6}
Eu-154	9.4×10^{4}	1,600			3,200	1.1×10^{5}	1,200	3.9×10^{4}
Eu-155	2.5×10^{4}	3,500			300	6.7×10^{4}	770	5,900
Fe-55	1.1×10^{4}	6,900			3,800	4.8×10^{5}	6,200	1.6
H-3	9,000	170			550	1.7×10^{4}	4,200	6,900
I-129	0.39	0.013			0.13	1.3	0.13	0.87
Kr-85	1.0×10^{5}	5.6			5,800	8.5×10^{4}	7,500	7.9×10^{4}
Np-237	7.6	0.62			0.15	5.6	1.9	11
Pa-231	0.0012	3.3×10^{-7}			9.1	0.061	0.0011	4.1
Pb-210	3.9×10^{-5}	$1.7\ 10^{-6}$			0.0011	3.2×10^{-4}	3.6×10^{-4}	7.3×10^{-4}
Pm-147	3.2×10^{5}	3.4×10^{4}			230	2.2×10^{5}	1.6×10^{4}	5,200
Pu-238	1.0×10^{5}	1.9×10^{4}	2.2×10^{5}	430	2,900	3.8×10^{4}	3,600	1.5×10^{5}
Pu-239	2,600	370	5,600	4,900	380	1.5×10^{5}	7,100	120
Pu-240	4,000	1,400	8,400	1,100	270	1.1×10^{5}	3,500	220
Pu-241	1.1×10^{6}	1.4×10^{5}	2.3×10^{6}	4.3×10^{4}	7.1×10^{4}	4.2×10^{6}	1.4×10^{5}	3.1×10^{4}
Pu-242	38	4.6	78.4	0.096	2.2	44	1.9	3.4
Ra-226	1.1×10^{6}	5.3×10^{-6}			0.0017	4.2×10^{6}	9.7×10^{-4}	0.0012
Ra-228		2.7×10^{-12}			0.35	0.012	2.4×10^{-5}	0.78
Ru-106	1.7×10^{5}	8.2×10^{4}			0.0035	1.2×10^{4}	1,100	0.65
Se-79	1.1				2.9	13	3.1	18
Sn-126		0.40			3.2	40	2.5	19
Sr-90	1.1×10^{6}	9,600			1.4×10^{5}	1.2×10^{6}	1.6×10^{5}	1.5×10^{6}
Tc-99	180	4.0			31	480	59	290
Th-229	2.2×10^{-5}	4.3×10^{-7}			4.9	0.029	1.8×10^{-4}	5.8
Th-230	0.010	6.5×10^{-4}			0.090	0.096	0.088	0.12
Th-232		3.7×10^{-12}			0.80	0.013	2.4×10^{-5}	2.5
Tl-208					1,100	2.5	0.020	580
U-232	0.86	5.2×10^{-5}	0.039		2,900	6.7	0.054	1,600
U-233	0.0022	1.5×10^{-4}	9.9×10^{-5}		2,500	7.7	0.039	1,800
U-234	26	2.5	1.2		74	270	190	240
U-235	0.29	4.6×10^{-5}	0.013	0.0071	0.53	12	0.082	3.6
U-236	5.7	0.0025	0.26		0.22	5.1	2.8	7.4
U-238	1.4	0.0034	0.066	0.44	0.11	5.0	2.1	0.045

Source: WGI 2008a, NRC 2005c, BMI 2007

[a] All values in curies.

[b] The inventories provided are truncated to match the nuclide list following nuclide screening provided in BMI 2007. The full inventories for the LWR and fast reactor fuels are provided in WGI 2008a.

Material and waste volumes and physical attributes including nuclide inventory, were based on the AFCF NEPA Data Study (WGI 2008a). Packaging assumptions for the materials were based upon the following source documents:

– AFCF NEPA Data Study, WGI 2008a;
– Engineering Alternative Studies for Separations NEPA Data Input Report, WSRC 2007; and
– Estimation of AFCF HLW and GTCC Waste Volumes to Support the GNEP Program PEIS (WGI 2008c).

Table 4.2 provides the number of containers per material type for each shipment analyzed for the domestic programmatic alternatives of this PEIS. These values are based upon the AFCF NEPA Data Study and the AFCF Waste Volumes Estimation White Paper (WGI 2008a, 2008c). Volumes per container type are also provided in the table as well as the limiting factor used to determine the bulk container volumes. It should be noted that there are some volume differences in HLW canister volume. This is largely due to differences in void space between the waste forms.

Table 4.3 provides the number of truck shipments necessary to meet the 200 GWe capacity. This generating capacity is estimated to be attained over an approximately 50-year project lifespan. Table 4.4 provides the number of rail shipments needed to meet the same capacity. These values were calculated on the basis of all shipments containing the same mass and volumes provided in the source documents. If the fast reactor and the recycling facility are collocated, the intersite transportation of fresh fast reactor fuel and spent fast reactor fuel would be eliminated. This would result in substantial decreases in the transportation impacts.

The cumulative values provided in Chapter 4 represent total exposure impacts over the entire affected population during the program period. It should not be assumed that affected populations (workers, driving crews, on-link traffic, etc.) receive multiple exposures. The cumulative exposure numbers were then multiplied by the 0.0006 dose conversion factor presented in ISCORS 2002 to provide an estimate of LCFs due to the transportation of the radioactive materials.

A more complete description of the amount of spent fuel processed and basis for materials generated by each domestic programmatic alternative are provided in Chapter 4. The mass or volume values provided were then used to calculate the number of containers required based on the NEPA source documents provided at the introduction of this section.

TABLE 4-2 – *Transportation Containers for Analyzed Shipments by Material Type*

Material to be Transported	Name of Canister or Cask	Volume or Mass per Container	Number of Containers per Shipment Truck (Rail)	Limiting Factor	External Exposure (mrem/hr)
LWR SNF	GA-4/9 or NLI–10/24	truck 2—MTHM rail—5 MTHM	1 (5)	Volume and thermal	10
Fresh LWR fuel [a]	--	6 MTHM	1	Volume and criticality	0.0521
SNF from MOX, thorium, HWR, and HTGR cycles	DOE SNF cask	truck—1 assembly rail—9 assemblies	1 (5)	Volume and Thermal	10
Fresh MOX fuel [a,b]	Class B cylindrical container	3 assemblies	1	Volume and criticality	2.52
Fresh thorium fuel [a]	--	1.7 MTHM	1	Volume and criticality	0.0521
Fresh HWR fuel [a]	--	3.24 MTHM	1	Volume and criticality	0.0521
Fresh HTGR fuel [a]	--	0.307	1	Volume and criticality	0.0521
Recovered uranium (oxide)	Class B 9975 drums	13.5 kg total U	15 (75)	Criticality	5
Recovered uranium (metal)	Class B 9975 drums	17.2 kg	18 (90)	Criticality	5
Fast reactor SNF	NLI-1/2 [c]	1 assembly	1 (5)	Thermal	10
Transmutation fuel	NLI-1/2	0.4 MTHM	1	Thermal and Criticality	10
Technetium, un-dissolved solids (UDS), and fuel cladding hulls in metal waste form [d, e]	HLW canister [f]	0.77 m^3	1 (5)	Volume	10
Lanthanides and other fission product waste [d]	HLW canister [f]	1.29 m^3	1 (5)	Volume	10
Cesium/strontium in hydroceramic waste form	Waste cans (3” IDx10’ long)	0.067 m^3	1 (5)	Thermal	10
GTCC LLW including absorbed/stabilized volatile fission products, spent equipment, and compacted HEPA filters.	HLW canister [f]	0.79 m^3	1 (5)	Volume	10
Low-level radioactive waste and mixed low-level radioactive waste.	B-25 Box	2.55 m^3	12 (60)	Volume	2

Source: WGI 2008a, WGI 2008c

[a] Transportation of fresh nuclear fuel is assumed to be via truck transport only. No specific transportation casks have yet been identified for the LWR, thorium, HWR , and HTGR fresh fuels transportation.

[b] Source NRC 2005c.

[c] Currently the NLI-1/2 is only certified for truck shipments. It is assumed that this cask or a similar model will be certified for rail transportation by the operational timeframe of this program.

[d] The HLW described in Chapter 4 is represented by two different waste streams; the Tc/UDS/hulls and Ln/fission product wastes. Tc/UDS/hulls wastes comprise approximately 45 percent of the total HLW by volume, and Ln/FP wastes comprise 55 percent.

[e] The metal hulls in this waste stream are assumed to be melted with the technetium and undissolved solids to act as a binding material.

[f] For the purposes of this analysis, some waste streams were assumed to be packaged in HLW canisters that would not be classified as HLW. Waste classification and selection of specific transportation casks would be completed as the facility design and waste characteristics are further developed.

TABLE 4-3—*Number of Shipments per Material Type - All-Truck Scenario – 200 GWe 200 Gigawatts Electric*

Material/Waste Type	No Action Alternative	All-Fast Recycle	Thermal/ Fast	Thermal Option 1	Thermal Option 2	Thorium Cycle	All-HWR	All-HTGR
LWR SNF	7.90×10^4	5.90×10^4	6.30×10^4	1.10×10^4	7.05×10^4	5.05×10^4	3.40×10^4	3.40×10^4
Fast reactor SNF		3.50×10^4	2.75×10^4					
Cs/Sr waste		1.08×10^4	1.08×10^4	1.08×10^4				
Ln/fission product waste [a]		2.25×10^4	2.21×10^4	2.13×10^4	1.30×10^4			
Tc/UDS/hulls waste [a]		3.11×10^4	3.06×10^4	2.94×10^4	1.80×10^4			
GTCC LLW	3,200	5.24×10^5	5.04×10^5	5.13×10^5	1.00×10^4	3,200	3,200	3,200
LLW	1.90×10^4	9.34×10^4	8.32×10^4	8.40×10^4	2.30×10^4	1.90×10^4	1.90×10^4	1.90×10^4
Recovered uranium (oxide)		1.64×10^4	1.83×10^4	2,920	1.90×10^4			
Recovered uranium (metal)		7,580	5,960					
MOX SNF [b]			8,000	1.95×10^5				
Thorium SNF						1.55×10^5		
HWR SNF					4.48×10^4		1.14×10^5	
HTGR SNF								1.56×10^6
Fresh LWR fuel	2.63×10^4	1.97×10^4	2.10×10^4	3,670	2.35×10^4	1.68×10^4	1.13×10^4	1.13×10^4
Transmutation fuel		3.50×10^4	2.75×10^4					
Fresh MOX fuel [c]			4,380	1.07×10^5				
Fresh thorium fuel						2.28×10^4		
Fresh HWR fuel					2.19×10^4		5.56×10^4	
Fresh HTGR fuel								1.05×10^5

[a] These two sources are combined in Chapter 4 analysis to represent high-level waste, or HLW.
[b] For this PEIS, HTGR SNF was assumed to be disposed in the form of whole fuel elements. This process has the disadvantage of requiring considerably more volume of storage of a unit weight of fuel and fission product isotopes. A typical DOE canister is sized to contain spent nuclear fuel assemblies' equivalent to a spent nuclear fuel quantity of about 1 MTHM. By comparison, an equivalent waste canister would contain a vertical stack of four fuel blocks (Fort St. Vrain type), or approximately 40 kg of heavy metal, requiring many more shipments of SNF when compared to other fuel cycle options (Shropshire and Herring 2004).
[c] The MOX spent fuel was assumed to be transported in DOE spent fuel canisters, with a capacity of 0.75 MTHM per container. Fresh MOX fuel was assumed to be transported in Class B containers as described in NRC 2005c. These containers have a capacity of 1.37 MTHM per shipment and are not appropriate for the shipment of spent fuel. Considering this, there would be approximately 83 percent more spent fuel shipments than fresh for the same amount of fuel. Shipment of the other fresh fuels assumed the same container as their spent fuel counterpart, with the same capacities.

TABLE 4-4—*Number of Shipments per Material Type - All-Rail Scenario – 200 GWe*

Material/Waste Type	No Action	All-Fast Recycle	Thermal/ Fast	Thermal Option 1	Thermal Option 2	Thorium Cycle	All-HWR	All-HTGR
LWR SNF	6,320	4,720	5,280	880	5,640	4,040	2,720	2,720
Fast reactor SNF		7,000	5,500					
Cs/Sr waste (aqueous process)		2,150	2,150	2,150				
Ln/fission product waste [a]		4,500	4,420	4,240	2,600			
Tc/UDS/hulls waste [a]		6,200	6,120	5,860	3,600			
GTCC LLW	630	1.03×10^5	8.23×10^4	1.01×10^5	2,000	630	630	630
LLW	3,800	1.89×10^4	1.66×10^4	1.70×10^4	4,500	3,800	3,800	3,800
Recovered uranium (oxide)		3,200	3,660	584	3,800			
Recovered uranium (metal)		1,520	1,190					
MOX SNF			178	4,330				
Thorium SNF						3,450		
HWR SNF					996		2,500	
HTGR SNF								3.30×10^4
Truck shipments of fresh fuel								
Fresh LWR fuel [b]	7.90×10^4	5.90×10^4	6.30×10^4	1.10×10^4	7.05×10^4	5.05×10^4	3.40×10^4	3.40×10^4
Transmutation fuel [b]		3.50×10^4	2.75×10^4					
Fresh MOX fuel [b]			4,380	1.07×10^5				
Fresh thorium fuel [b]						1.55×10^5		
Fresh HWR fuel [b]					4.48×10^4		1.14×10^5	
Fresh HTGR fuel [b]								1.56×10^6

[a] These two sources are combined in Chapter 4 analysis to represent high-level waste, or HLW

[b] All shipment of fresh nuclear fuel is assumed be to via truck transport.

5. INCIDENT-FREE IMPACTS METHODOLOGIES

5.1 Radiological Impacts

Radiological dose during normal, incident-free transportation of radioactive materials results from exposure to the external radiation from the shipping containers. The dose to a receptor is a function of proximity to the radiation source exposure time, and the intensity (source strength) of the radiation.

For the purpose of providing a conservative estimate of impacts, exposure rates assumed are considered to be larger than what is expected to be observed during normal operations. As represented in Table 4-2, many of the material packages assume the regulatory maximum exposure rate of 10 mrem/hour at a distance of 6.6 ft (2 m) from the source.

Table 5.1-1 provides the suggested vehicle speeds for truck and rail transport for use in RADTRAN analysis as provided in Neuhauser and Kanipe (2000) and Chen et al. (2002). The vehicle speed is used in the incident-free portion of the risk assessment. In conjunction with the distance traveled, the vehicle speed determines the amount of time the transportation crew, the on-population and the off-link population are exposed to external radiation from the shipping package.

TABLE 5.1-1—*RADTRAN Suggested Vehicle Speeds*

Population Zone	Truck Speed [mph (km/h)]	Rail Speed [mph (km/h)]
Rural	55 (88.49)	40 (64.37)
Suburban	25 (40.25)	25 (40.25)
Urban	15 (24.16)	15 (24.16)

Sources: Neuhauser and Kanipe (2000); Chen et al. (2002)

Radiation doses and collective doses were determined for workers (including vehicle crews) and the general population from normal, incident-free transportation. The truck crew was the vehicle drivers. For rail shipments, the crew was defined as workers in close proximity to the shipping containers during inspection or classification of railcars. The general population was the individuals within 2,625 ft (800 m) of the road or railway (off-link), sharing the road or railway (on-link), and at stops. Collective doses for the crew and general population were calculated using the RADTRAN 5.6/RADCAT 2.3 computer codes (Weiner et al 2006).

For the worker populations, the following scenarios were analyzed:

- An inspector 3.3 ft (1 m) from the rail or truck container. The person would be expected to be exposed to the spent fuel casks for one hour per cask. For other shipping configurations, it was assumed that an inspector would be exposed to each trailer for one hour (Jason 2001);
- A truck driver and passenger, serving as an escort, that would be expected to drive radioactive shipments for 1,000 hours per year and unload shipments for 1,000 hour/yr; and
- A railyard worker working at a distance of 33 ft (10 m) from the shipping container for two hours.

For rail shipments, the following scenarios for members of the public were considered:

- A resident living 98 ft (30 m) from the rail line where the shipping container was being transported; and
- A resident living 656 ft (200 m) from a rail stop where the shipping container was sitting for 20 hours. This population is considered to be “Nearby Residents” in the results provided in Chapter 11.

For truck shipments, the three scenarios for members of the public were:

- A person caught in traffic and located 13 ft (4 m) away from the surface of the shipping container for 30 minutes;
- A service station worker working at a distance of 66 ft (20 m) from the shipping container for 1 hour; and
- A resident living 98 ft (30 m) from the highway used to transport the shipping container. This population is considered to the “Nearby Residents” in the results provided in Chapter 11.

Dose to MEI and impacts were estimated for the cumulative operations of the alternatives analyzed. However, for the scenario involving an individual caught in traffic next to a truck, the radiological exposures were calculated for only one event because it was considered unlikely that the same individual would be caught in traffic next to all containers for all shipments. For truck shipments, the maximum exposed transportation worker is the driver who was assumed to drive shipments for up to 1,000 hours per year. In the maximum exposed individual scenarios, the exposure rate for the shipments depended on the type of waste being transported. Also, the maximum exposure rate for the truck driver was 2 mrem per hour (10 CFR 71.47(b) (4)).

Transporting spent fuel and other selected radioactive materials would require the use of physical security and other escorts for the shipments. Regulations require that two individuals serve as escorts for truck shipments traveling through highly populated (urban) areas (10 CFR Part 73.37). One of the escorts must be in a vehicle that is separate from the shipment vehicle. For rail shipments in urban areas, at least two escorts must maintain visual surveillance of a shipment from a railcar that accompanies a cask car.

For legal-weight truck shipments, the analysis assumed that a second driver, who would be a member of the vehicle crew, would serve as an escort in all areas. The analysis assigned a second escort for travel in urban areas and assumed that this escort would occupy a vehicle that followed or led the transport vehicle by at least 197 ft (60 m). The analysis assumed that the dose rate at a location 6.5 ft (2 m) behind the vehicle would be 10 mrem per hour, which is the limit allowed by the DOT regulations (49 CFR part 173.441). Using this information, the analysis used the RISKIND computer code to calculate a dose rate of 0.11 mrem per hour for the escort located 197 ft (60 m) behind the transport vehicle (Yuan et al. 1995). The value for an escort vehicle ahead of the transport vehicle would be lower. Because the dose rate in the occupied crew area of the transport vehicle would be less than two mrem per hour, the dose rate two meters in front of the vehicle would be much less than 10 mrem per hour, the value assumed for a location two meters behind the vehicle. The value of 2 mrem per hour in normally occupied areas of transport vehicles is the maximum allowed by the DOT regulations (49 CFR 173.441). This exposure analysis for escorts follows methods used in the Yucca Mountain FEIS assessment (Jason 2001).

For rail shipments, it was assumed that the escorts would be 98 ft (30 m) away from the shipping cask. This is due to the length of a buffer car 59 ft (15 m), the normal separation between cars (6.5 ft [2 m] for two cars), the distance from the end of a cask to the end of the rail car (16.5 ft [5 m]), and the assumed distance from the escort car's near end to the occupants (nearly 33 ft [10 m]). Using the assumed dose rate of 10 mrem per hour at a distance of two meters from the cask, RISKIND calculated an estimated dose rate of 0.46 mrem per hour for the occupied area of the escort car. Two-hour stops were assumed to occur every 170 mi (277 km) (BMI 2007). For rail shipments requiring intermodal transfer to barge or trucks (legal weight or heavy-haul), a 30-hour stop was assumed. The visual surveillance must be maintained at railyard transfers. Escorts would be present in the escort car from the time the train was assembled at the generator site until it reached its final destination at the repository.

In the international shipments analysis provided in Chapter 7, shipment of spent fuel from the port of entry to a recycling center was analyzed using risk factors for work and general populations provided in the Yucca Mountain FEIS (DOE 2002i). These factors were used to calculate the incident-free impacts and still keep a generic routing assumption, congruent with the rail and truck transportation analyses.

5.2 Nonradiological Vehicle Emissions

Incident-free nonradiological vehicle emission fatalities were estimated using unit risk factors. These fatalities would result from exhaust and fugitive dust emissions from highway and rail traffic and are associated with 10-micrometer particles. The nonradiological unit risk factors were adopted from the transportation analysis conducted for the Yucca Mountain FEIS (DOE 2002i). The unit risk factors used in this analysis are 1.5×10^{-11} and 2.6×10^{-11} fatalities per kilometer per persons per square kilometer for diesel truck and rail modes of transport respectively. For escort vehicles and commuter vehicles, the vehicle emission unit risk factor was 9.4×10^{-12} fatalities per kilometer per person per square kilometer (Jason 2001).

6. ACCIDENT RISK ANALYSIS METHODOLOGIES

The offsite transportation accident analysis considers the impacts of accidents during the transportation of waste by truck or rail. Under accident conditions, impacts to human health and the environment may result from the release and dispersal of radioactive material. Transportation accident impacts have been assessed using accident analysis methodologies developed by the NRC. This section provides an overview of the methodologies (NRC 1977b; Fischer et al. 1987; Sprung et al. 2000). Accidents, some of which could potentially breach the shipping container are represented by a spectrum of accident severities and releases of radioactive material. Historically, most transportation accidents involving radioactive materials have resulted in little or no release of radioactive material from the shipping container. Consequently, the analysis of accident risks takes into account a spectrum of accidents ranging from high-probability accidents of low severity to hypothetical high-severity accidents that have a correspondingly low probability of occurrence.

The impacts for specific alternatives were calculated in units of dose and collective dose. Impacts are further expressed in terms of estimated latent cancer fatalities (LCF). The conversion factor of 0.0006 LCF/person-rem was provided by the Interagency Steering Committee on Radiation Standards report (ISCORS 2002).

6.1 Accident and Fatality Rates

For calculating accident risks and consequences, state-specific accident rates were taken from data provided in Saricks and Tompkins (1999) for rail, barge, and heavy combination trucks. The rates provided in Saricks and Tompkins are based upon state-specific accident and fatality rate data for 1994 to 1996. Subsequent studies by the Federal Motor Carrier Safety Administration found that accidents were underreported by approximately 39 percent and fatalities were underreported by approximately 36 percent (UMTRI 2003). To account for the underreporting, DOE increased the state-specific truck and fatality accident rates from Saricks and Tompkins by factors of 1.57 and 1.64 to its analysis for the *Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County , Nevada* (DOE 2008f).

6.2 Conditional Probabilities and Release Fractions

Accident severity categories for potential radioactive waste transportation accidents are described in three NRC reports: NUREG-0170 (NRC 1977b) for radioactive waste in general; a report commonly referred to as the Modal Study (Fischer et al. 1987); and a reassessment of NUREG-0170 (Sprung et al. 2000). The latter two reports address only spent nuclear fuel. The Modal Study represents a refinement of the NUREG-0170 methodology, and the reassessment analysis, *Re-Examination of Spent Fuel Shipment Risk Estimates* (Sprung et al. 2000), which compares more recent results to NUREG-0170, represents a further refinement of both studies. This later reference was the basis for the conditional probabilities and release fractions used in this analysis.

Re-Examination of Spent Fuel Shipment Risk Estimates (Sprung et al. 2000) represents the severe accident environment as a matrix, with one dimension being the temperature of the radioactive material and the other being the velocity of impact onto an unyielding surface. The matrix contains 19 cases for the truck accidents and 21 cases for rail accidents. The unique feature of the most recent analysis is the specification of a fire-only case. The result is ultimately reduced to a conditional probability of occurrence for each accident case or category, and a set of radionuclide release fractions for each accident case or category.

As stated in the West Valley Demonstration Project Waste Management EIS (DOE 2004f), the two studies detailed above can be applied to waste types other than spent fuel. In the WVDP EIS, release fractions and conditional probabilities are provided for a wide range of materials and the corresponding transportation containers. Tables 6.2-1 through 6.2-6 provide the conditional probabilities and release fractions associated with the domestic programmatic spent fuel shipments. Tables 6.2-7 and 6.2-9 provide conditional probabilities and release fractions utilized for shipments containing HLW canisters, 9975 containers, and the Class B truck containers used to transport fresh MOX fuel, respectively. Table 6.2-10 provides the conditional probabilities and release fractions associated with the barge transport of spent fuel analyzed in the international shipment scenario (Chapter 7).

TABLE 6.2-1—*Conditional Probabilities and Release Fractions for LWR, MOX, and Thorium Cycle Spent Fuel Shipments – Truck Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.06×10^{-5}	1.36×10^{-1}	4.09×10^{-9}	1.02×10^{-7}	1.02×10^{-7}	1.36×10^{-3}
3	5.86×10^{-6}	8.39×10^{-1}	1.68×10^{-5}	6.71×10^{-8}	6.71×10^{-8}	2.52×10^{-3}
4	4.95×10^{-7}	4.49×10^{-1}	1.35×10^{-6}	3.37×10^{-7}	3.37×10^{-7}	1.83×10^{-3}
5	7.49×10^{-7}	8.35×10^{-1}	3.60×10^{-5}	3.77×10^{-6}	3.77×10^{-6}	3.16×10^{-3}
6	3.00×10^{-10}	8.40×10^{-1}	2.40×10^{-5}	2.15×10^{-5}	5.01×10^{-6}	3.17×10^{-3}

Source: Jason 2001.

TABLE 6.2-2—*Conditional Probabilities and Release Fractions for HWR Spent Fuel Shipments – Truck Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.22×10^{-5}	5.66×10^{-5}	3.54×10^{-7}	2.29×10^{-8}	1.83×10^{-9}	5.71×10^{-6}
3	5.59×10^{-6}	0.0	0.0	0.0	0.0	0.0
4	5.60×10^{-7}	7.86×10^{-4}	1.42×10^{-7}	6.63×10^{-8}	5.80×10^{-8}	1.93×10^{-4}
5	6.99×10^{-8}	4.00×10^{-3}	7.87×10^{-5}	4.72×10^{-6}	3.20×10^{-8}	6.35×10^{-5}
6	2.24×10^{-10}	7.70×10^{-3}	2.74×10^{-4}	7.57×10^{-5}	3.68×10^{-7}	1.13×10^{-3}

Source: BMI 2007.

TABLE 6.2-3—*Conditional Probabilities and Release Fractions for HTGR Spent Fuel Shipments – Truck Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.22×10^{-5}	0.0	0.0	0.0	0.0	0.0
3	5.59×10^{-6}	0.0	0.0	0.0	0.0	0.0
4	5.60×10^{-7}	7.50×10^{-4}	5.63×10^{-10}	5.63×10^{-10}	5.63×10^{-10}	0.0
5	6.99×10^{-8}	0.0	0.0	0.0.	0.0	0.0
6	2.24×10^{-10}	3.52×10^{-3}	2.72×10^{-9}	2.64×10^{-9}	2.64×10^{-9}	0.0

Source: BMI 2007.

TABLE 6.2-4—*Conditional Probabilities and Release Fractions for LWR Spent Fuel, MOX Spent Fuel, and Thorium Cycle Spent Fuel Shipments – Rail Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.9991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	1.96×10^{-1}	5.87×10^{-9}	1.34×10^{-7}	1.34×10^{-7}	1.37×10^{-3}
3	4.91×10^{-5}	8.39×10^{-1}	1.68×10^{-5}	2.52×10^{-7}	2.52×10^{-7}	9.44×10^{-3}
4	5.77×10^{-7}	8.00×10^{-1}	8.71×10^{-6}	1.32×10^{-5}	1.32×10^{-5}	4.42×10^{-3}
5	1.10×10^{-7}	8.35×10^{-1}	3.60×10^{-5}	1.37×10^{-5}	1.37×10^{-5}	5.36×10^{-3}
6	8.52×10^{-10}	8.47×10^{-1}	5.71×10^{-5}	1.43×10^{-5}	1.43×10^{-5}	1.59×10^{-2}

Source: BMI 2007.

TABLE 6.2-5—*Conditional Probabilities and Release Fractions for HWR Spent Fuel Shipments – Rail Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.9991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	2.84×10^{-4}	1.71×10^{-6}	3.91×10^{-7}	1.10×10^{-8}	2.96×10^{-5}
3	4.91×10^{-5}	0.0	0.0	0.0	0.0	0.0
4	5.77×10^{-7}	2.13×10^{-3}	2.36×10^{-6}	3.55×10^{-6}	3.55×10^{-6}	1.18×10^{-2}
5	1.10×10^{-7}	4.00×10^{-3}	7.87×10^{-5}	1.77×10^{-5}	9.68×10^{-8}	1.61×10^{-4}
6	8.52×10^{-10}	4.68×10^{-2}	9.63×10^{-4}	2.47×10^{-4}	2.73×10^{-6}	7.17×10^{-3}

Source: BMI 2007.

TABLE 6.2-6—*Conditional Probabilities and Release Fractions for HTGR Spent Fuel Shipments – Rail Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.9991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	1.02×10^{-4}	6.12×10^{-11}	6.12×10^{-11}	6.12×10^{-11}	0.0
3	4.91×10^{-5}	0.0	0.0	0.0	0.0	0.0
4	5.77×10^{-7}	4.77×10^{-3}	7.89×10^{-8}	7.89×10^{-8}	7.89×10^{-8}	0.0
5	1.10×10^{-7}	0.0	0.0	0.0	0.0	0.0
6	8.52×10^{-10}	1.70×10^{-3}	2.84×10^{-8}	2.62×10^{-8}	2.62×10^{-8}	0.0

Source: BMI 2007.

TABLE 6.2-7—*Conditional Probabilities and Release Fractions for HLW Box Shipments*

Severity Category	Truck		Rail	
	Conditional Probability	Release Fraction	Conditional Probability	Release Fraction
1	0.99993	0	0.99991	0
2	6.2×10^{-5}	3.4×10^{-8}	3.9×10^{-5}	6.2×10^{-8}
3	5.6×10^{-6}	0	4.9×10^{-5}	0
4	5.2×10^{-7}	2.4×10^{-7}	5.8×10^{-7}	7.9×10^{-6}
5	7.0×10^{-8}	9.3×10^{-8}	1.1×10^{-7}	9.3×10^{-8}
6	2.2×10^{-10}	3.0×10^{-7}	8.5×10^{-10}	2.7×10^{-6}

Source: DOE 2004f

TABLE 6.2-8—*Conditional Probabilities and Release Fractions for 9975 Container Shipments*

Severity Category	Truck		Rail	
	Conditional Probability	Release Fraction	Conditional Probability	Release Fraction
1	0.99993	0	0.99991	0
2	6.2×10^{-5}	2.6×10^{-5}	3.9×10^{-5}	2.5×10^{-5}
3	5.6×10^{-6}	2.4×10^{-5}	4.9×10^{-5}	5.6×10^{-6}
4	5.2×10^{-7}	2.6×10^{-5}	5.8×10^{-7}	5.2×10^{-7}
5	7.0×10^{-8}	6.2×10^{-5}	1.1×10^{-7}	7.0×10^{-8}
6	2.2×10^{-10}	6.7×10^{-5}	8.5×10^{-10}	2.2×10^{-10}

Source: DOE 2004f

TABLE 6.2-9—*Conditional Probabilities and Release Fractions for Class B Cask for Fresh MOX Fuel*

Severity Category	Truck	
	Conditional Probability	Release Fraction
1	0.99993	0
2	6.2×10^{-5}	6×10^{-8}
3	5.6×10^{-6}	2×10^{-7}
4	5.2×10^{-7}	2×10^{-6}
5	7.0×10^{-8}	2×10^{-5}
6	2.2×10^{-10}	2×10^{-5}

Source: NRC 2005c.

TABLE 6.2-10—*Conditional Probabilities and Release Fractions for LWR Spent Fuel Shipments by Barge*

Severity Category	Conditional Probability	Release fractions for PWR assemblies				
		Gases	Cesium	Ruthenium	Particulates	CRUD
1	0.994427	0.0	0.0	0.0	0.0	0.0
2	0.00500	0.196	5.87×10^{-9}	1.34×10^{-7}	1.34×10^{-7}	0.00137
3	5.00×10^{-6}	0.839	1.68×10^{-5}	2.52×10^{-7}	2.52×10^{-7}	0.00944
4	5.00×10^{-4}	0.800	8.71×10^{-6}	1.32×10^{-5}	1.32×10^{-5}	0.00442
5	0.0	0.835	3.60×10^{-5}	1.37×10^{-5}	1.37×10^{-5}	0.00536
6	1.3×10^{-6}	0.847	5.71×10^{-5}	4.63×10^{-5}	1.43×10^{-5}	0.0159

Source: DOE 2002i.

7. SEVERE TRANSPORATION ACCIDENT ANALYSIS METHODOLOGIES

DOE assessed the consequences of severe transportation accidents; such accidents with a frequency of about 1×10^{-7} per year are known as maximum reasonably foreseeable transportation accidents. According to DOE guidance, accidents that have a frequency of less than 1×10^{-7} rarely need to be examined (DOE 2002d).

The analysis was based on the 21 rail accident severity categories identified in Sprung et al 2000. Each of the 21 accident cases has an associated conditional probability of occurrence (NRC 2000). Combining the conditional probabilities analyzed in the domestic programmatic and AFCF assessments, only Cases 1, 4, and 20 of the document have occurrence frequencies greater than 1×10^{-7} per year for the rail shipment of LWR SNF. Case 20 is estimated to have the higher consequences and was thus assumed to be the maximum reasonably foreseeable transportation accident. This case was applied to all the other materials analyzed, using the release fractions provided in Section 6.2 above. Table 7-1 provides the annual frequencies estimated for the accident severity cases provide in Sprung et al. 2000.

Rail shipments were estimated to have higher accident impacts given the higher material inventories per shipment. The PWR LWR spent fuel case is analyzed because the maximum load is larger than BWR [5.0 metric tons heavy metal (MTHM)/cask compared to 4.8 MTHM/cask]. The following assumptions were made in analyzing the impacts of the maximum foreseeable accident scenarios:

- A release height of the plume of 33 ft (10 m) for fire and impact-related accidents. In the case of an accident with fire, a 33 ft (10 m) release height with no plume rise from the buoyancy of the plume due to fire conditions would yield higher estimates of consequences than accounting for the buoyancy of the plume from the fire;
- A breathing rate for individuals of 367,000 ft^3 (10,400 m^3) per year (Neuhauser and Kanipe 2000);
- A short-term exposure to airborne contaminants of two hours;
- A long-term exposure time to contamination deposited on the ground for one year, with no interdiction or cleanup (BMI 2007); and
- Low wind speeds and stable atmospheric conditions (a wind speed of 2 m/hr [0.89 m/s] and Class F stability). The atmospheric concentrations estimated from these conditions would be exceeded only five percent of the time.

DOE used the RISKIND 2.0 code (Yuan et al. 1995) to estimate the radiation doses for the inhalation, groundshine[1], immersion, and resuspension pathways.

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[1] Groundshine is defined as gamma radiation emitted from radioactive materials deposited on the ground.

TABLE 7-1—*Annual Frequencies for Accident Severity Cases*

Accident Severity Case	Annual Frequency (Accidents per Year)
1	2.46E-07
2	1.71E-08
3	1.35E-10
4	8.90E-07
5	2.48E-08
6	3.31E-09
7	2.03E-09
8	5.65E-11
9	7.55E-12
10	1.41E-10
11	3.94E-12
12	5.23E-13
13	1.11E-12
14	3.10E-14
15	4.12E-15
16	1.25E-11
17	7.55E-15
18	5.23E-16
19	4.12E-18
20	1.48E-06

The analysis assumed that the severe transportation accidents could occur anywhere. Population densities in rural areas range from 0 to 139 people per km^2. DOE based the analysis on the rural area on a population density of six people per km^2, which is a representative population density for a rural area. For analysis for the Yucca Mountain Project transportation impacts, DOE estimated the population density in a urban area by identifying the 20 urban areas in the U.S. with the largest populations using 2000 census data, determining the population density in annular rings around the center of each urban area, escalating these population densities to 2067, and averaging the population densities in each successive annular ring. These values were assumed for the maximum foreseeable impact assessment for this PEIS. The values are provided in Table 7-2 (DOE 2008f).

TABLE 7-2—*Population Density in Urban Areas*

Annular Distance (mi)	Population Density (/mi^2 [/km^2])
0 to 5 (0 to 8.05 km)	12,980 (5,012)
5 to 10 (8.05 to 16.09 km)	7,656 (2,956)
10 to 15 (16.09 to 24.14 km)	5,470 (2,112)
15 to 20 (24.14 to 32.19 km)	3,476 (1,342)
20 to 25 (32.19 to 40.23 km)	2,330 (899)
25 to 50 (40.23 to 80.47 km)	774 (299)

Source: DOE 2008f.

8. REFERENCES

10 CFR Part 71	NRC, " Packaging and Transportation of Radionuclide Material," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, Revised January 1, 2003.
10 CFR Part 73.37	NRC, "Requirements for Physical Protection of Irradiated Reactor Fuel in Transit," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC, Revised January 1, 2003.
49 CFR Part 173	US Department of Transportation, "Shippers--general requirements for shipments and packagings," Title 49, Subtitle B, Chapter 1, *Code of Federal Regulations*, National Archives and Records Administration, Washington, D.C., Revised October 1, 2007.
49 CFR Part 397	US Department of Transportation, "Transportation of Hazardous Materials; Driving and Parking Rules," *Code of Federal Regulations*, National Archives and Records Administration, Washington, D.C., Revised October 1, 2007.
BLS 2006	BLS 2006, "Occupational Injuries and Illnesses (Annual), Table 1, Incidence Rates of Nonfatal Occupational Injuries and Illnesses by Industry and by Case Types, 2005," U.S. Department of Labor, Bureau of Labor Statistics, Washington, D.C. Available at: http://stats.bls.gov/news.release/osh.toc.htm. Accessed, November 1, 2007.
BLS 2007	BLS, "Census of Fatal Occupational Injuries (CFOI), All Charts – Census of Fatal Occupational Injuries," U.S. Department of Labor, Bureau of Labor Statistics, Washington, D.C., 2007, Available at: http://stats.bls.gov/iif/oshcfoi1.htm . Accessed, November 1, 2007.

BMI 2007 — Battelle Memorial Institute, "Calculation Report for the Transportation Impacts for the Draft Supplemental Environmental Impact Statement for a Geological Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada," Calculation Report Number BCO-006, Battelle Memorial Institute, Columbus, Ohio, October 4, 2007.

Chen et al. 2002 — Chen, S.Y., Monette, F., Biwer B.M., "A Resource Handbook on DOE Transportation Risk Assessment," National Transportation Program, U.S. Department of Energy, Albuquerque Office
Albuquerque, New Mexico, July 2002.

DOE 1995d — DOE, "DOE Programmatic Spent Nuclear Fuel Management and INEEL Environmental Restoration and Waste Management Programs Final Environmental Impact Statement," US Department of Energy, Idaho Operations Office, Idaho Falls, Idaho, April.

DOE 1995e — DOE, "Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement," DOE/EIS-0203, U.S. Department of Energy, 1995.

DOE 2002d — DOE, "Recommendations for Analyzing Accidents under the National Environmental Policy Act," U.S. Department of Energy, Environment, Safety and Health, Office of NEPA Policy and Compliance, July 2002, Available at: http://www.eh.doe.gov/nepa/tools/guidance/analyzingaccidentsjuly2002.pdf#search=%22Recommendations%20for%20Analyzing%20Accidents%20under%20the%20National%20Environmental%20Policy%20Act%22, Accessed on January 15, 2008.

DOE 2002i — DOE, "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada," Volume II, Appendix A, DOE/EIS-0250, U.S. Department of Energy, Washington DC, February, 2002.

DOE 2004f	DOE, "West Valley Demonstration Project Waste Management Final Impact Statement," US Department of Energy West Valley Area Office, West Valley, New York, DOE/EIS-0337, U.S. Department of Energy, January 2004.
DOE 2004j	DOE, "Source Term Estimates for DOE Spent Nuclear Fuels," DOE/SNF/REP-078, Rev. 1, US Department of Energy, Idaho Operations Office, Idaho Falls, Idaho.
DOE 2008f	DOE, "Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada," DOE/EIS-0250F-S1D, U.S. Department of Energy Office of Civilian Radioactive Waste Management, Las Vegas, NV, July, 2008.
Fischer et al. 1987	L.E. Fischer, C.K. Chou, M.A. Gerhard, C.Y. Kimura, R.W. Martin, R.W. Mensing, M.E. Mount, and M.C. White, "Shipping Container Response to Severe Highway and Railway Accident Conditions," Report No, NUREG/CR-4829, U.S. Nuclear Regulatory Commission, Washington, D.C., 1987.
FMCSA 2007	Federal Motor Carrier Safety Administration (FMCSA), "Large Truck Crash Facts 2005," FMCSA-RI-07-046, U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Washington, D.C., February 2007.
ISCORS 2002	Interagency Steering Committee on Radiation Standards (ISCORS), "A Method for Estimating Radiation Risk from Total Effective Dose Equivalent (TEDE)," ISCORS Technical Report, 2002.
Jason 2001	Jason Technologies, "Transportation Health and Safety Calculation/Analysis Documentation in Support of the Final EIS for Yucca Mountain Respository," CAL-HSS-ND-000003, Las Vegas, Nevada.
Johnson and Michelhaugh 2003	Johnson, P.E., and R.D. Michelhaugh, "Transportation Routing Analysis Geographic Information System (TRAGIS) User's Manual," Report No, ORNL/NTRC-006, Oak Ridge National Laboratory, Oak Ridge, Tennessee, June 2003.

Neuhauser and Kanipe 2000	Neuhauser, and F.L., Kanipe, “RADTRAN 5, User Guide,” SAND2000-1257, Sandia National Laboratories, Albuquerque, New Mexico, 2000.
NRC 1977b	U.S. Nuclear Regulatory Commission (NRC), “Final Environmental Impact Statement on the Transportation of Radioactive Material by Air and Other Modes,” Office of Standards Development, U.S. Nuclear Regulatory Commission, Washington, DC, December 1977.
NRC 2000a	NRC, “Reexamination of Spent Fuel Shipment Risk Estimates,” J.L. Sprung, D.J. Ammerman, N.L.Breivik, R.J. Dukart, F.L. Kanipe, J.A. Koski, G.S. Mills, K.S. Neuhauser, H.D. Radloff, R.F. Weiner, and H.R. Yoshimura, NUREG/CR-6672, U.S. Nuclear Regulatory Commission, Washington, DC, March 2000.
NRC 2005c	NRC, “Environmental Impact Statement on the Construction and Operation of a Mixed Fuel Fabrication Facility at the Savannah River Site, South Carolina,” NUREG-1767, U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation, Washington, DC, February 2005.
NRC 2006c	NRC, “Environmental Impact Statement for an Early Site Permit (ESP) at the Exelon ESP Site,” NUREG-1815, Vol. 1, U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation, Washington, DC, July 2006.
Saricks and Tompkins 1999	Saricks, C.L., and M.M. Tompkins, “State-Level Accident Rates of Surface Freight Transportation: A Reexamination”, Report No. ANL/ESD/TM-150, Argonne National Laboratory, Argonne, Illinois.
Shropshire and Herring 2004	Shropshire, David E., Herring, Stephen J., “Fuel-Cycle and Nuclear Material Disposition Issues Associated with High-Temperature Gas Reactors” Idaho National Engineering and Environmental Laboratory (INEEL), ANES 2004, Miami Beach, Florida, October 3-6, 2004.
Sprung et al, 2000	J.L. Sprung, D.J. Ammerman, N.L.Breivik, R.J. Dukart, F.L. Janipe, J.A. Koski, G.S. Mills, K.S. Neuhauser, H.D. Radloff, R.F. Weiner, and H.R. Yoshimura, “Reexamination of Spent Fuel Shipment Risk Estimates,” NUREG/CR-6672, U.S. Nuclear Regulatory Commission, Washington, DC, March 2000.

UMTRI 2003 — University of Michigan Transportation Institute, 2003, “Evaluation of the Motor Carrier Management Information System Crash File, Phase One,” UMTRI 2003-6, University of Michigan, Ann Arbor, Michigan.

Weiner et al. 2006 — R.F. Weiner, T.J. Heames, D. Hinojosa, D.S. Mills, D.J. Orcutt, and D.M. Osborne, “RadCat 2.3 User Guide”, Report No. SAND2006-6315, Albuquerque, NM: Sandia National Laboratories, October 2006.

WGI 2008a — Washington Group International (WGI), “Advanced Fuel Cycle Facility Conceptual Design and NEPA Support Activities (NEPA Data Study),” AFCF-ST-001, Rev. 1, Washington Group International, Western Operations Center, Denver, CO, April 2, 2008.

WGI 2008c — WGI, “Estimation of AFCF HLW, LLW and TRU-Contaminated Waste Volumes to Support the GNEP PEIS,” AFCF-WP-00-003, Rev. A, Washington Group International, Western Operations Center, Denver, CO, April 8, 2008.

Yuan et al. 1995 — Yuan, Y.C., S.Y. Chen, B.M. Biwer, D.J. LePoire, “RISKIND - A Computer Program for Calculating Radiological Consequences and Health Risks from Transportation of Spent Nuclear Fuel,” ANL/EAD-1, Argonne, Illinois: Argonne National Laboratory, 1995.